ANTARCTIC ICE...
GOING, GOING, GONE?

As ice on the frozen continent melts, scientists examine the climate change clues captured in layers of snow that are several centuries old, writes Nerilie Abram

T WAS JANUARY 2008 and I was on the back deck of HMS Endurance, wearing a full-body survival suit and eager for the short helicopter ride that would take me onto Antarctic ice for the first time. The ship was travelling through the channel that divides James Ross Island from the Antarctic Peninsula – a trip that would have been impossible not so long ago.

Since the 1990s, a series of ice shelves along the Antarctic Peninsula have collapsed, including the ice shelf that had once permanently connected James Ross Island to the rest of the continent. Most famously, the collapse of the nearby Larsen B ice shelf was captured by satellite photographs. These images have been held up as an example of climate change happening before our eyes. But are they? This was what I was here to find out.
The Antarctic Peninsula is warming quickly. Over the last 50 years the climate here has warmed three times faster than the global average. The problem is that temperature measurements in this remote region don't go much further back than that. So how can we put the current warming into perspective? The answer lies locked within Antarctica’s ice. The ice blanketing most of the Antarctic continent is made of snow that has fallen and been buried. Scientists use these ancient ice layers as a window into Earth’s past climate.

The deepest parts of Antarctica’s great ice sheets might hold a climate record that goes back more than 1 million years. In the 2014 summer, scientists from the Australian Antarctic Division will lead an ice-drilling expedition to Aurora Basin. This is part of a coordinated international effort towards the most ambitious and technically challenging piece of ice core research ever attempted – the quest for Antarctica’s ‘oldest ice’.

For the much smaller James Ross Island ice-drilling project, our team of seven scientists and engineers lived and worked in tents on the ice for almost two months. The top 283 metres of this ice cap consists of snow that’s built up over the past 1000 years. We know the age of the snow layers by counting the yearly summer-winter cycles of chemical impurities, such as sea salt in the ice, and by the fixed time markers left in the snow by ash from volcanic eruptions.

To build a record of how temperature changed in the past, we measure the proportion of heavy versus light water molecules, or isotopes, in the ice. Isotopes are versions of the same element that have different numbers of neutrons, so have different masses. In ice we measure the number of water molecules that have a heavy hydrogen atom (deuterium, with an atomic mass of 2) compared to those with the light hydrogen atom (atomic mass of 1). The heavy molecules take more energy to move through the water cycle, and in warm climates more of these heavy molecules will reach Antarctica and fall as snow. So the proportions of these molecules act as a ‘thermometer’ for the past.

The isotopes in the James Ross Island ice core tell us the coolest time on the Antarctic Peninsula was around 600 years ago. Back then the climate was around 1.6°C cooler than today. The ice also confirms that the warming here since the 1920s has been
James Ross Island is a ‘Goldilocks’ location for exploring the connection between temperature and ice melt. It is not so cold that summer temperatures are never high enough for melting to occur, and neither is it so warm that extensive melting destroys the climate record locked in the ice.

exceptionally fast – faster than at almost any other time in the past 1000 years.

But this particular ice core reveals much more about the changing climate on the Antarctic Peninsula. James Ross Island is a ‘Goldilocks’ location for exploring the connection between temperature and ice melt. It is not so cold that summer temperatures are never high enough for melting to occur, and neither is it so warm that extensive melting destroys the climate record locked in the ice. Serendipitously, conditions on this ice cap are just right for preserving a rare history of summer ice melt.

The 1.6°C of warming over the past 600 years may not sound significant, but it’s caused a tenfold increase in the amount of summer melting on James Ross Island. Most of this intensification of ice melt occurred in the past few decades. This unique history of summer ice melt is a powerful illustration of how environmental changes in a warming climate don’t always occur gradually.

Ice melt is an example of a threshold in Earth’s environment. When summer temperatures remain below 0°C, no melting occurs. But as the climate warms towards this threshold, on some days in summer the temperature will go above 0°C and there will be excess energy to melt the surface snow. Any further warming will increase the number of days that go over the melting threshold, and increase the level they exceed it by. In this way, a small increase in average temperature can cause a large increase in melting.

So are images like the Larsen B ice shelf collapse evidence for recent climate change? Measurements from the ice core say they are. It shows us that rising temperatures have taken summer ice melt on the Antarctic Peninsula to a level unprecedented for at least the past 1000 years. Ice melt is a critical process that weakens the structure of ice shelves and glaciers, and satellite images show that extensive summer melting caused the visually dramatic Larsen B collapse. Ice melt also has real implications for rising sea levels across the world.

**ANTARCTICA’S ROLE IN GLOBAL SEA LEVEL RISE**

Rising sea levels in a warming world is particularly relevant to Australia as large proportions of our population and infrastructure are near the coast.

In 2013, the Intergovernmental Panel for Climate Change (IPCC) released its fifth assessment report. On our current emissions trajectory it projects that sea level is likely to rise by between 0.53 and 0.97 metres by 2100. This projection takes into account the thermal expansion of the oceans as they warm, as well as changes in snowfall, surface melting and glacier loss that will alter the quantity of ice locked up on land. What these model-based projections aren’t yet able to assess is the possibility of accelerating ice flow and loss from Antarctica’s vast ice sheets.

Antarctica’s contribution to sea level is a balancing act between ice accumulation across the central plateaus and ice loss around the margins of the continent. Satellite monitoring of Antarctica’s ice sheets over the past few decades has revolutionised our understanding of this changing balance. These satellite measurements use changes
in the height or gravitational pull of the ice sheets to identify places where Antarctica is gaining or losing ice.

Overall, Antarctica is losing ice, accounting for just under 10 per cent of the rise in global sea level over the past two decades. The mountain glaciers and ice caps along the Antarctic Peninsula are losing around 20 billion tonnes of ice yearly. Even more significant is the approximately 65 billion tonnes of ice lost each year from West Antarctica.

This is just the tip of the iceberg, so to speak. West Antarctica has been described as the ‘weak underbelly’ of Antarctica’s ice sheets. This ice sheet sits on bedrock, but that ground is below sea level – by more than 2 kilometres in some places. This makes the ice sheet vulnerable to melting from beneath. As the margins of the West Antarctic Ice Sheet melt and thin, seawater warm enough to melt the ice is able to encroach further under the ice sheet, and this could cause ice to be lost even faster. The latest IPCC report flags the possibility that rapid collapse of parts of the West Antarctic Ice Sheet could cause sea level to rise substantially above its current projections.

Earth’s past provides some evidence to gauge how quickly ice could be lost from Antarctica in the future.

The last time the Earth’s temperature was similar to today – around 125,000 years ago – sea level was roughly 6 metres higher and changed twice as fast as the sea level rise we’ve seen in the past decade. What this demonstrates is the ability for sea level to respond to climate warming at a speed that matches the upper end of IPCC projections for the 21st century.
The frozen continent: The locations discussed in this essay are shown on a satellite image mosaic of Antarctica. The lower panels show satellite images captured during the Larsen B ice shelf collapse in 2002. Extensive melt ponds were visible on the ice shelf in late January, which weakened its structure and, over the space of just a few weeks, more than 3200 square kilometres of the ice shelf disintegrated. The nearby Larsen A and Prince Gustav ice shelves were also lost in the decade before the Larsen B collapse.
Sea level in the past closely followed the changes in polar temperatures recorded by ice cores. This connection provides another way to determine the possible trajectory of future sea level rise. There are uncertainties in this approach, but the observed relationship between temperature and sea level since the 1880s indicates that the IPCC’s estimates for future sea level rise may be too low. Projected warming for the coming century points to the possibility that sea level could rise by as much as 1.9 metres by 2100.

The potential for rapid changes in ice melt and loss in Antarctica presents an enormous challenge for Australia’s efforts to plan adequately for rising sea levels. Scientists will continue to unlock the clues that Antarctica’s vast ice sheets contain about her past. This will provide a long-term context that is critical to our understanding of the changes we are now seeing – and those that lie ahead for Antarctic ice.

**ALL THINGS ICE**

**Ice sheets** are large domes of land ice. The East Antarctic Ice Sheet occupies over 75 per cent of the continent and holds the equivalent of 53 metres of sea level. The smaller but less stable West Antarctic Ice Sheet has the equivalent of 4.3 metres of sea level locked within it. Ice caps are small versions of ice sheets.

**Glaciers** are like rivers of flowing ice. They are found on the edges of Antarctica’s ice sheets and along the mountainous Antarctic Peninsula. At the coast, the ice from glaciers can break away as icebergs, or feed into a floating ice shelf.

**Ice shelves** are where Antarctica’s land ice extends out over the sea. Because ice shelves are floating, their ice has already contributed to global sea level. Ice shelves act as a buttress for the glaciers behind them. When they are lost the flow of glacier ice into the ocean speeds up. Around 28,000 square kilometres of ice shelf area around Antarctica has been lost since the 1950s.

**Sea ice** forms when the ocean’s surface freezes. In winter, the sea ice around Antarctica effectively doubles the size of the continent. Sea ice doesn’t have any influence on sea level, but it is important for climate through the exchange of carbon dioxide between the ocean and the atmosphere and because it is white, the surface absorbs less heat than the dark ocean.

**FURTHER READING**


Rising greenhouse gas emissions are warming the marine environment with unprecedented consequences, writes Elvira Poloczanska

We live in a naturally variable world. The climate system contains phenomena such as El Niño-Southern Oscillation and the Indian Ocean Dipole that affect Australia’s climate and beyond, over time-scales that range from years to many decades. (See: See-saws and boys and girls).

But we are heading into the unknown. Increasing levels of greenhouse gases in the atmosphere are associated with warming in the climate system, including both the atmosphere and ocean. Insidious and pervasive changes to components of the climate system are unprecedented, and in this case over time-scales ranging from decades to hundreds of thousands of years. Land and water temperatures are increasing, sea levels are rising, wind patterns and ocean currents are changing and the oceans are acidifying (See: Ocean acidification). The natural world is in continuous ebb and flow in response to such climate variability. So why is climate change any different?

For a start, not only are human-induced, ‘anthropogenic’, greenhouse gas emissions leading to changes unprecedented in the historical record, but the rate of many of these changes will be rapid, possibly too rapid for some components of the natural world to adjust.
Impacts of recent climate change have been observed via the responses of hundreds of individual species and fundamental ecosystem processes. An international team, led by me and Commonwealth Scientific and Industrial Research Organisation (CSIRO) colleague Anthony Richardson, has pooled information from many studies and all of the oceans to show a global fingerprint of the impact of recent climate change on ocean life. From microscopic plankton floating at the ocean surface, to sea turtles migrating across entire ocean basins, marine life is being affected by anthropogenic climate change.

In Australian oceans, tropical and subtropical species of fish, molluscs and plankton are shifting southward as waters warm, while cool-water seaweeds are in decline on both sides of the continent. Mass coral bleaching has occurred regularly on the Great Barrier Reef.

The see-sawing of sea surface temperatures between the eastern and western Indian Ocean is known as the Indian Ocean Dipole. A ‘positive’ dipole phase is associated with cooler than normal sea temperatures north-west of Australia and the eastern tropical Indian Ocean, and a decrease in rainfall over parts of central and southern Australia. A ‘negative’ phase produces warmer than normal waters off Australia’s north-west coast and an increase in rainfall over parts of southern Australia.

The El Niño-Southern Oscillation (ENSO) is the dominant mode of year-to-year climate variability observed globally. ENSO oscillates between ‘El Niño’ (the boy) and ‘La Niña’ (the girl) conditions. El Niño refers to extensive warming of the eastern tropical Pacific Ocean which leads to a major shift in weather patterns across the Pacific. El Niño is associated with warmer than normal sea temperatures during late summer off northern and eastern tropical Australia and a decrease in winter, spring, and summer rainfall over much of eastern Australia.
since the early 1980s; yet no evidence of mass coral bleaching was reported in the scientific literature prior to this time. Australian scientists have worked with data from scientific surveys, statistical and mathematical models and information supplied by fishers, divers and citizen scientists (see: *Travels of a big barnacle and little snails*) to provide conclusive evidence of these recent impacts.

Further changes to the climate, and therefore the natural world, are highly likely to continue. It’s time to focus on actions.

**ADAPTING TO CLIMATE CHANGE**

In order to prosper in a changing climate, industries and societies must be agile and adaptable. The process of adapting to climate change is already underway in Australia.

Scientists are producing much-needed information to assist ocean managers and policy makers to help marine ecosystems and industries adapt. For example, fishery managers may need to consider management changes as fish species move across state boundaries or as stock productivity changes. Decisions will be informed by a variety of research methods, including regional climate models, fisheries assessment models, biodiversity surveys, habitat mapping, and even whole ecosystem models such as ‘Atlantis’.

Developed by the CSIRO’s Beth Fulton, Atlantis considers biophysical, economic and social components of marine ecosystems.

With adaptation planning we can capitalise on opportunities and reduce losses; however, we are likely to face ecological ‘surprises’. For instance,
having species of tropical fish turning up further south may be good news for recreational fishermen and divers, who will have new species to ‘bag’, but such range shifts may also bring challenges.

Case in point: the grazing urchin, *Centrostephanus rodgersii* (pictured above), has greatly multiplied in numbers and spread down the Tasmanian coastline in response to warming and a strengthening of the East Australian Current. It has begun to change the structure of Tasmanian kelp communities with detrimental effects on coastal biodiversity including commercial species such as abalone and lobster.

Researchers Scott Ling and Craig Johnson, with the Institute for Marine and Antarctic Studies in Tasmania, showed that over-fishing of large lobsters, one of the urchin’s chief predators, has helped urchins to overgraze important kelp-bed habitat. Adapting fishery management to enhance stocks of larger lobsters could be a win-win situation, benefiting both the fishery and the kelp ecosystem.

Australia is a land of extremes. It suffers floods and heatwaves, summer cyclones batter tropical coasts and winter storms drench southern coasts. Such extreme events give a glimpse of life in a warmer world and allow researchers to develop and test adaptation responses. In the summer of 2010-11, an unusual ‘marine heatwave’ occurred in the coastal waters off central Western Australia. An unusual coincidence of climatic events led to water temperatures 5°C above normal, which lasted for some ten weeks.

The effects were profound. Widespread ‘die-offs’ of fish, seaweeds and shellfish occurred and tropical species moved farther south temporarily. Whale sharks and manta rays were

---

**OCEAN ACIDIFICATION**

Atmospheric carbon dioxide, released by human activities, is entering the world’s oceans, making them more acidic. There is growing evidence that even relatively minor perturbations in ocean chemistry could lead to profound changes in the marine environment. We only have to look at the research of CSIRO, Australian Institute of Marine Science, University of Queensland, James Cook University, and the Antarctic Climate and Ecosystems Cooperative Research Centre (CRC) to understand that the whole ocean, from tropics to poles, is acidifying.

Ocean acidification not only affects the ability of corals and other animals and plants to form shells and skeletons of calcium carbonate, it can also disrupt basic physiological and behavioural processes of fish.

We have very sophisticated approaches to examine the impacts of ocean acidification in Australia. These include global and regional ocean models, mini coral reefs in experimental tanks, and aquaria for rearing larval fish. Scientists have also undertaken research expeditions to natural carbon dioxide seeps found in shallow waters off Papua New Guinea, where the gas bubbles from the ocean floor due to volcanic activity. These seeps give us a glimpse of coral reefs in an acidified ocean, and such reefs are not the rich and beautiful complex of thousands of coral species we see elsewhere today, even just a few kilometres from the seeps. Instead these acidified reefs are dominated by a few slow-growing species and are not able to support the high diversity of life we see on coral reefs today.
Clues to the impacts of climate change far offshore can be discovered closer to home, along Australia’s rocky coastline. Scientists comprehensively surveyed shores in Queensland, New South Wales, Victoria, South Australia and Tasmania during the 1950s and 1960s, a stretch of some 4000 kilometres and a major undertaking at the time. These extensive broad-scale surveys mapped the distributions of intertidal plants and animals and give a baseline against which to compare shores today.

We recently revisited many of the historical survey sites in south-eastern Australia and found shifts in the distribution of some intertidal barnacles and snails consistent with the rapid warming in the region. The most striking shift was that of the giant rock barnacle *Austromegabalanus nigrescens*. We’re confident the barnacle was absent from Tasmania in the 1950s as the scientists made a special effort to look for it and noted in their field books that they were ‘very surprised’ they couldn’t find it anywhere in Tasmania.

Today the barnacle occurs from Eddystone Point in the extreme north-east of Tasmania down to the Tasman peninsula. Observations of the barnacle in Tasmania exist for the north-eastern coast from the late 1980s, so it must have arrived in Tasmania sometime before this.

We need your help to chart the changes taking place in Australia. Join the ClimateWatch program and report the species you find when you visit the coast or go for a walk. Information can be either entered on the website or by downloading the ClimateWatch app.

By getting involved, you can help scientists understand how climate change is impacting Australian ecosystems.

**We must keep our focus on reducing anthropogenic greenhouse gases in the atmosphere.**

**Adaptation Research**

Scientists use monitoring to underpin adaptation research. The Australian Integrated Marine Observing System (IMOS) monitors boundary currents and continental shelf waters for changes in their physical (temperature, salinity, and currents), chemical (nutrients and carbon) and biological (plankton and top predators) characteristics using state-of-the-art technology such as ocean gliders (see picture), moorings, floats and satellite imagery. This national observation system is advancing understanding of climate variability and change, and providing an early warning system for major changes that might occur.

At the CSIRO Climate Adaptation Flagship, teams of climate scientists, conservation biologists, ecologists, social scientists, engineers and economists work together to develop and inform adaptation approaches. Adaptation is not just about technological and engineering approaches, but also about knowledge delivery and education. These include delivering bespoke seasonal forecasts to aquaculture facilities along coastlines, delivering future scenarios of climate and natural systems to policy-makers, and synthesising observed and expected impacts for the public and decision-makers.

Climate change is only one pressure on our natural world but it will force us to explore new pathways and to think ‘outside the box’ as we face new combinations of environmental conditions. For example, we may need to breed new aquaculture species that are suited to future climates, to translocate vulnerable plants and animals to new locations where they can survive, to build safety margins into fishery harvest levels to account for uncertainty in climate change impacts, and to remove hard barriers, such as walls and buildings, to allow...
mangroves and salt marshes to retreat as sea levels rise. Understanding the genetic basis of adaptation within species will help us to understand their vulnerabilities to climate change and allow us to ensure that gene combinations able to confer resilience to future climate change prevail.

BEYOND ADAPTATION
Investment in adaptation planning now can fortify us for the inevitable changes to come, but we still need to look at the big picture. There may be thresholds beyond which we can’t adapt, and unexpected challenges to face.

We must not take our focus off our primary goal, which should always be mitigation. If we want our children and our children’s children to enjoy a rich and varied natural world, to have food security and enjoy the privileges of the technology we enjoy, we must keep our focus on reducing anthropogenic greenhouse gases in the atmosphere.

**FURTHER READING**
Poloczanska, E.S. et al 2013, ‘Global imprint of climate change on marine life’, *Nature Climate Change* 3(10), 919-925 (or read a summary at The Conversation).

**DR ELVIRA POLOCZANSKA** is a research scientist at the CSIRO Marine and Atmospheric Research Division. She specialises in climate change ecology, ecological modelling and coastal ecosystems.
CHAPTER 2: LIVING IN A CHANGING ENVIRONMENT

ADAPTATION IS THE KEY TO SURVIVAL

Raging bushfires, torrential rain, floods and droughts are warnings that it’s time for Australia to change its ways, writes David Bowman

RECENTLY, I VISITED the Australian Alps – the landscape that inspired me to become a landscape ecologist. My boyhood memories from 40 years ago were confronted by a fire-blasted landscape. More than 90 per cent of the Australian Alps bioregion has been burnt in a series of massive bushfires since the start of this century. At my old school, nestled in the foothills of the Alps, I discovered a state-of-the-art fire bunker with its own water, power and air supply designed to provide refuge in case of another extreme bushfire.

This experience highlights the fact that when people are confronted by a direct environmental threat they change behaviour. They adapt. But adaptations can be economically costly, socially disruptive and in some cases environmentally damaging, so there must be clear and compelling evidence that what has worked in the past will not work in the future. This is a job for science and scientists. We can – and should – play a pivotal role in determining when, how and why Australia responds to environmental change.
MORE SEVERE BUSHFIRES?

Extreme environmental changes, such as bushfires, have always occurred because we’re on a dynamic, living planet. What is at stake is whether our society and economy can persist if the rate of environmental changes abruptly increases. For instance, a massive surge in bushfires worldwide could, in principle, accelerate climate change by releasing massive stores of carbon dioxide (CO₂) and soot, which will lead to warmer and drier climates favouring yet more fires. Even a moderate increase in fire activity will provide a brake on Australia’s economy, given the economic and social impacts of these disasters.

Determining whether bushfires have increased in severity would be possible if perfect historical records existed, stretching back thousands of years. Unfortunately, in Australia there are very few detailed historical records of natural phenomena or variation in the geographic patterns of plant and animal populations.

To build a picture of past environmental changes, scientists use ‘environmental archives’ such as sediments in lakes, tree rings, and historical records of landscapes made by painters, photographers, and explorers. These data provide a baseline to determine if current environmental conditions are outside the range of natural variability.

Currently in Australia, the historical data are too sparse to answer the question unambiguously of whether bushfire activity is within or outside the range of historical variability. Nor is there enough evidence to determine if climate change or the cessation of Aboriginal landscape burning is causing bigger and more intense fires; only through increased investment in scientific research can these issues be resolved.

Satellites, airborne sensors and computer networks are creating a revolution in the capacity to record bushfires across landscapes. These monitoring systems provide essential information about fire activity which can be analysed to understand better the success and failure of fire management approaches and the effects of fire on plants and animals.

HUMAN ADAPTABILITY

Humans have a remarkable ability to adapt to threats. It’s what our ancestral Homo sapiens did for hundreds of thousands of years and it’s what we’re doing today.

For instance, there’s growing awareness among people living in flammable environments about the need to fireproof homes and have gardens with non-flammable plants. More planned burning is being carried out to reduce fire hazards.

Because one size does not fit all, scientists must discover how to achieve sustainable co-existence with bushfires. For specific ecosystems, we need to know what is true and what is not, what is practical and cost effective and what is not.

For example, the heated debate about whether cattle grazing in the Australian ecosystems reduce bushfires is based on slender evidence and is context-specific.

In certain types of ecosystems, such as semi-arid rangelands, grazing may reduce fire severity by controlling rampant invasive non-native grass. These grasses can fuel fires of sufficient intensity to kill trees, degrading wildlife habitat. But in other ecosystems, such as the Australian Alps, evidence shows grazing does not reduce bushfire severity. Instead, it causes substantial ecological damage, such as trampling fragile bogs and fouling creek lines.

ADAPTIVE MANAGEMENT

Adaptation to environmental change can involve trial and error to find solutions to problems. Science, using logic and experimentation, has a vital role in fast-tracking this process. Case in point: prescribed burning. Scientific analyses
show the real benefit of planned burning in protecting lives and property comes from burning bushland close to houses. Yet research also shows such burning causes smoke pollution which can harm health, albeit less than that from intense bushfires. By combining this knowledge it’s possible to determine the risk-reduction benefit of planned burning while minimising exposure of vulnerable people to smoke.

A cycle of clarifying problems, designing interventions and monitoring the outcome is often called ‘adaptive management’. For instance, as a consequence of the recommendation of the 2009 Bushfire Royal Commission, Victoria is almost tripling the amount of planned burning across the state. But in addition to this increase the Royal Commission also recommended monitoring and evaluating the impact of the burning to understand the effect on biodiversity and the environment.

The application of adaptive management will become increasingly important as we humans are forced to respond to the multiple challenges of changing environmental conditions, increasing human populations and strains on ecosystems globally.

**ADAPTATION, SCIENCE AND GLOBAL ENVIRONMENTAL CHANGE**

Global environmental change is the signature tune of the 21st century. Indeed, some scientists suggest we should recognise the planet has shifted into a new geological epoch, one they call the Anthropocene.

This is the case because humans have become major actors in the functioning of the Earth system – be it by accelerating geological processes, modifying local, regional and global climate patterns, restructuring ecosystems through extinctions and introducing plants and animals, or by modification of landscapes through damming rivers, clearing forests, cultivating grasslands and mining ore deposits.

Science and technology are crucial to mitigating the effects of these changes. Already on the table are confronting options such as geoengineering – large-scale intervention in Earth’s climate system to reduce global warming – and new ecosystem construction using novel combinations of plants and animals and modified species rejigged by biotechnology for conservation or adaptation. Such options raise profound ethical questions, extending beyond the reach of science alone.
I owe my career to an inspiring school teacher who opened my eyes to the power of science to help us understand the natural environment. I was lucky. Over the past 40 years, numerous scientific discoveries have changed the way Australians think and feel about the bush. Among the important contributions made by scientists has been the recognition that, along with drought and floods, bushfires have shaped our “wide brown land”. We must coexist with these powerful natural forces, and science provides the key to this urgent adaptive process.

**SMOKE**

It’s obvious. Where there’s smoke there’s fire; where there’s fire there’s smoke; and where there’s smoke there are respiratory and other health disorders. But surprisingly, until a decade ago, smoke from bushfires was seen as a minor nuisance rather than a substantial health risk.

To manage bushfire smoke better, a research program is being conducted that combines studies of human health, landscape ecology and atmospheric effects. Funded by the Australian Research Council, the project, which began in 2001, includes representatives from land management, environmental protection and health departments in the Northern Territory, Tasmania, New South Wales and Western Australia.

Already, results clearly demonstrate that smoke produced from severe and even low-level bushfires can adversely affect human health. People at highest risk are the very old or the very young, or those who live with chronic medical conditions such as asthma or heart disease.

The project has contributed to improved guidelines for land management, environment protection and public health practice. For example, in Tasmania a network of smoke-monitoring sites was established and its real-time pollution readings are linked to health advice and information for the general public.

This example shows how science can help the community adapt to bushfire smoke pollution, and tolerate the effects of planned burns designed to reduce the risk to life and property from uncontrolled bushfires. Given the many challenges faced by those in bushfire regions – including urban development adjacent to bushland, hotter and drier climates, and the need to reduce smoke pollution further – it is vital that scientific research efforts are sustained.

**FURTHER READING**


BIOWEALTH: ALL CREATURES GREAT AND SMALL

Australia’s financial wealth, health and wellbeing depend on its biowealth – the diversity of species that support all life, writes Corey Bradshaw

As I stepped off the helicopter’s pontoon and into the swamp’s chest-deep, tepid and opaque water, I experienced for the first time what it must feel like to be some other life form’s dinner. As the helicopter flittered away, the last vestiges of that protective blanket of human technological innovation flew away with it.

Two other similarly susceptible, hairless, clawless and fangless Homo sapiens and I were now in the middle of one of the Northern Territory’s largest swamps at the height of the crocodile-nesting season. We were there to collect crocodile eggs for a local crocodile farm that, ironically, has assisted the amazing recovery of the species since its near-extinction in the 1960s. Removing the commercial incentive to hunt wild crocodiles by flooding the international market with scar-free, farmed skins gave the dwindling population a chance to recover.

Conservation scientists like me rejoice at these rare recoveries, while many of our fellow humans ponder why we want to encourage the proliferation of animals that can easily kill and eat us. The problem is, once people put a value on a species, it is usually consigned to one of two states. It either flourishes as do domestic crops, dogs, cats and livestock, or dwindles towards or to extinction. Consider bison, passenger pigeons, crocodiles and caviar sturgeon.
As a conservation scientist, it’s my job not only to document these declines, but to find ways to prevent them. Through careful measurement and experiments, we provide evidence to support smart policy decisions on land and in the sea. We advise on the best way to protect species in reserves, inform hunters and fishers on how to avoid over-harvesting, and demonstrate the ways in which humans benefit from maintaining healthy ecosystems.

*Homo sapiens* is a relatively new addition to the global species pool collectively called ‘biodiversity’. Like other species and physical processes before us, we have changed our planet’s biosphere in a geological heartbeat. Many geologists argue that the planet has entered a new geological era – the Anthropocene – which is characterised by the human-caused signal of mass extinction above the normal rate at which species vanish.

Extinction generally comes in waves – so-called mass extinction events. Prior to the Anthropocene, five mass extinction events have occurred since the Cambrian period about 500 million years ago. The Permian extinction (250 million years ago) was the worst. Roughly 95 per cent of all species on Earth disappeared. The most infamous mass extinction happened about 65 million years ago during the Cretaceous period when a giant asteroid struck Earth, killing off most dinosaurs.

But the Anthropocene shows extinction rates exceeding the background rate – the rate between mass events – by up to 10 000 times. Of course, scientists debate the true inflation factor due to the difficulty of observing extinctions. (See: *Counting species one by one*). Regardless, it’s clear the planet is losing biodiversity at an alarming rate.

Given the realities of daily life, it’s easy to forget that biodiversity is important to our wellbeing. Australians feel they are in touch with the bush, but the fact is most do not appreciate the natural world on which they utterly depend.

It’s not hyperbole, naïveté or green platitudes – all people depend absolutely on every other species. For instance, consider the very air we breathe. Nearly all the oxygen in the atmosphere is produced by plants and much of that by marine algae. Yet worldwide we treat oceans like giant toilets and cut down forest blocks every year that, together, equal the size of Tasmania.

On the topic of plant respiration – the process of photosynthesis in which plants take up carbon dioxide and release oxygen – the world is now faced with centuries of tumultuous climate disruption from industrial emissions, yet more than a third of the world’s carbon is stored in forests. In other words, more forests equals less carbon dioxide in the atmosphere and slower, less intense climate change.

Much of the food grown to feed the seven billion-strong human population is pollinated by a wide array of animals, and most of that is done by a single species – the honeybee. Yet bee populations around the world are crashing because of forest fragmentation and our overuse of pesticides. No pollination, fewer crops. And most of the world’s drinking water comes mainly from natural...
waterways and wetlands that filter out the contaminants people produce.

Other examples of 'ecosystem services’ abound. Even the much-maligned shark is an essential ecosystem engineer. Wherever shark populations are abundant and diverse, reefs are healthier, fish populations are higher and water clarity is better.

This happens because large sharks impose a top-down pressure on smaller predators, thus limiting the latter’s intake of other fish species. Removing the biggest predators means that smaller predators increase, which then quickly eat other species that keep things like algae in check. The overall effect is a biologically poor system, prone to further degradation.

Even the feared dingo plays an essential ecosystem role. Wherever scientists have looked, areas with large dingo populations have more native marsupials. Where dingos are poisoned or fenced out, native mammals do not do well.

Why? Dingoes outcompete and kill introduced cats and foxes. Australia's estimated 18 million feral cats, in particular, are a biodiversity scourge. To illustrate, imagine a line of stock trucks bumper-to-bumper along the 600 kilometres from Sydney to Grafton. Each is filled to the brim with native animals: possums, bandicoots, penguins, lizards, skinks and so forth. This represents how many native animals are killed each year by feral cats.

Little wonder then that Australia has the world’s worst record for mammal extinctions.

If one considers the totality of all these different interactions, dependencies and functions – the scientific discipline of

**COUNTING SPECIES ONE BY ONE**

It is easy to be impressed when considering the variety of life on Earth, known collectively as biodiversity. Conservative estimates place the number of species in different groups living today at more than 4 million protists – microorganisms without a cell nucleus – 75,000-300,000 helminth (worm) parasites; 1.5 million fungi, 320,000 plants, 4-6 million arthropods (insects and the like), 30,000 fishes, 6500 amphibians, 10,000 reptiles, 10,000 birds and around 5000 mammals.

While scientists are confident they have inventoried most of the larger species, such as mammals and birds, estimates of the number of smaller, more cryptic species are highly uncertain. In fact, total estimates range from only several million to several hundred million species worldwide. Both extremes seem unlikely.

The term biodiversity itself is a variable concept. The simplest way of estimating it is to count the number of species within a given area. But this belies its complexity. Biodiversity includes, among many other things, genetic diversity, ecological function, and the way in which species’ composition changes over space and time. Simply adding up the number of species, therefore, ignores important factors like ‘endemism’ – species found nowhere else – rarity, genetic variation, resilience, and evolutionary potential, and the ability to adapt to environmental change by evolving. It’s hardly surprising that people often have difficulty grasping the importance and complexity of biodiversity, especially considering our increasingly nature-disconnected lifestyles.

Another important aspect of biodiversity is how much of it is disappearing, and at what rate. Extinction might appear obvious because it ultimately involves comparing a time when a species was present to another when it is no longer. Unfortunately, it’s not that straightforward. Even the date of the infamous dodo extinction is uncertain, with claims it survived another 30 years beyond its last sighting.

The problem lies in the fact that as population abundance declines it is more difficult to detect remaining individuals, especially in the case of already rare and cryptic species. For example, would anyone even notice if a rare species of underground fungus went extinct? The answer is: only if someone had already been documenting its distribution and decline. Expand that to the millions of species on the planet, combined with the uncertainty associated with that number itself, and it becomes clear why estimates of extinction rates are highly uncertain.
ecology – the logical conclusion is that all biodiversity can be considered under the umbrella of ‘biowealth’.

This concept encapsulates the two most important elements of biodiversity from a human perspective. The first is that diversity is an essential requirement for life. Without all, or at least most, of these species, we humans inevitably lose important services. Secondly, this diversity provides humanity – largely free of charge – with the elements essential for survival. Without biodiversity we are poor. With it we are ‘biorich’.

So consider the crocodiles, sharks and snakes, the small and the squirmy, the smelly, slimy and scaly. Consider the fanged and the hairy, the ugly and the cute alike. The more we degrade this astonishing diversity of evolved life and all its interactions on our only home, the more we expose ourselves to the ravages of a universe that is inherently hostile to life.

It is time to embrace, protect and cherish Australia’s biowealth so our children can live happy, prosperous lives. It is time to build biodiversity into daily life by regularly reporting the state of the nation’s biowealth alongside economic, sport and stock market indices. Only then will society be cognisant of, and perhaps stimulated to improve, the state of Homo sapiens’ one and only life-support system.

FURTHER READING


PROFESSOR COREY BRADSHAW
is Director of Ecological Modelling at The University of Adelaide’s Environment Institute. He specialises in applying mathematical approaches to measure the effect of humans on biodiversity and investigates the ways in which a prosperous human society can co-exist and benefit from healthy, natural ecosystems. He is a leading authority on biodiversity, with over 200 scientific publications and a popular conservation blog (ConservationBytes.com).