Unravelling the mysteries of land and sea

Graeme O'Neill recalls advances and challenges in environmental science that *Ecos* has chronicled in its first 25 years.

W van Aken

Australia's rainforests constitute an authentic Cretaceous Park of green dinosaurs. Of the 14 families that botanists class as most primitive among flowering plants, 12 can be found in Australia's rainforests – more than in Africa, Asia or South America.

When *Ecos* was born in 1974, Australia was considered a land of eucalypts, acacias and banksias, with a few patches of rainforest imported second-hand from Asia.

In less than 150 years, logging and land clearing for dairy and sugarcane farms had consumed three quarters of our tropical and subtropical rainforests, leaving only 0.5% of their pre-European area intact.

It was a 1980 article in *Ecos* that ignited the revolution in rainforest conservation, and a phase-change in the nation's consciousness. Much of what remains of Australia's rainforests now lies safely within the Wet Tropics World Heritage Area, and an archipelago of national parks down the length of the east coast.

Rainforest ecologists Dr Len Webb and Jeff Tracey, of the former Division of Tropical Crops and Pastures, chose *Ecos* to tell Australians that the 19th century English botanist Joseph Hooker and his intellectual heirs had been mistaken.

Despite the obvious similarities that misled Hooker, Australia's rainforests are not hand-me-downs from Asia, but as indigenous to the continent as its distinctive hard-leaved 'native' vegetation. They are the remnants of formerly extensive tropical and sub-tropical rainforests that clothed Australia when it was warmer and wetter, and still lay in the embrace of the mother continent, Gondwana.

Continuing research by CSIRO rainforest ecologists and their university colleagues has confirmed Webb and Tracey's hypothesis that Australia's rainforests have seen repeated cycles of expansion and contraction during the past two million years, retreating to protected, permanently wet areas during arid glacial periods. Their species are ancient, but in their latest incarnation, our rainforests are less than 10 000 years old.

Guidance from above

During the past quarter of a century, computers and remote-sensing satellites have transformed our understanding and management of the Australian continent and its resources. Australians owe a particular debt to two CSIRO researchers, Dr Ken McCracken and Dr Andy Green, who pioneered the remote-sensing industry while at the former Division of Mineral Physics.

Today, remote-sensing satellites keep watch over our agriculture, and track environmental change such as desertification, deforestation, salinisation and the evolution of floods and droughts. Satellites have provided us with an eagle-eye view of the continent's unique and ancient geology, and guided minerals-exploration companies to prospective new provinces.

We also rely on satellites to monitor changing sea-surface temperatures that modulate Australia's climate, and to track currents and slow-moving eddies that influence the success of fisheries such as the tuna and western rock lobster fisheries.

CSIRO climatologists and oceanographers, and their colleagues in the Bureau of Meteorology, have given us a new understanding the forces that shape Australia's erratic climate.

The terms El Niño and La Niña are now part of the Australian lexicon. Any sustained downward trend in the barometric pressure differential between Darwin and Tahiti – the so-called Southern Oscillation index – may signal the onset of an El Niño event.

Climatologists can now forewarn farmers, water-management authorities and natural disaster organisations in eastern Australia at least six months in advance of impending El Niño events that cause severe drought and potentially catastrophic bushfire such as the Ash Wednesday conflagration of February, 1983. Conversely, a rising trend in the Southern Oscillation index, combined with warming sea-surface temperatures around northern Australia, may be the overture to drought-breaking La Niña rains, destructive cyclones and storms, and severe flooding.

In recent years we have learned that El Niño is one member of a Trinity of climatic

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phenomena that influence Australia's climate. CSIRO oceanographers have identified a region in the Indian Ocean south of Java, where huge eddies of warm water bleed through the Indonesian island arc from the south-west Pacific, creating long-lived pools of warm water. Intense evaporation and convection from the so-called Indian Ocean dipole send bands of rain-bearing cloud diagonally across the Australian continent, bringing rain to the south-east. When the dipole enters a cool phase, the moisture supply shuts off.

The Trinity's third component takes the form of two very long, low, slow-moving waves that constantly circle Antarctica clockwise, at 180° to each other. The water mass within the peaks of these Antarctic circumpolar waves is about a degree warmer than in the intervening troughs. As they wash along Australia's southern coastline, they induce a cycle in which warmer, wetter conditions follow cooler, drier conditions at approximately 18-month intervals.

When climatologists develop a model that accurately simulates the interactions between all three phenomena, they should be able to predict climatic trends across Australia a year or more in advance.

Another predicted trend in the global climate, and a threat to terrestrial and marine ecosystems across the globe, now appears to be materialising: global warming caused by the torrent of greenhouse gases entering the atmosphere as a result of human activity.

At Cape Grim, CSIRO researchers are monitoring rising levels of carbon dioxide, methane and nitrogen oxides that conspire with CFCs and halons to induce atmospheric warming, by marginally reducing the amount of heat radiated from the Earth's surface back into space.

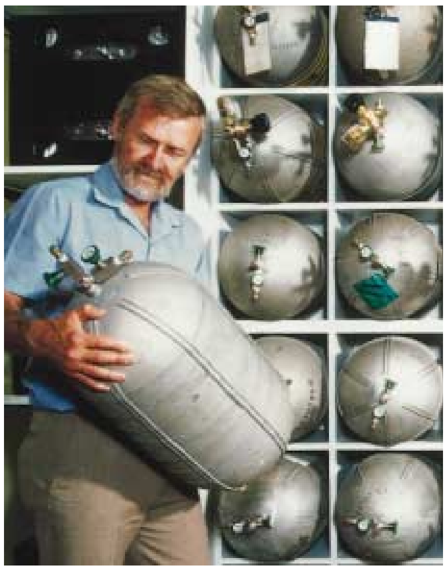
Many indicators, including rising average temperatures in temperate and polar latitudes – particularly night minima – melting glaciers and polar sea-ice sheets, an apparent increase in the frequency of extreme weather events, and a host of environmental and biological phenomena, now point to the onset of global warming. The question is no longer whether, but when, the enhanced greenhouse effect will materialise from the obscuring mist of natural climatic variation.

CSIRO researchers are working to predict how Australia's climate may change in a global warming regime, and to assess its likely impacts on the environment, agriculture and other industries, and on human health and wellbeing. Global warming is imminent, but with the current state of climate modelling, and science's incomplete understanding of the global climate system,

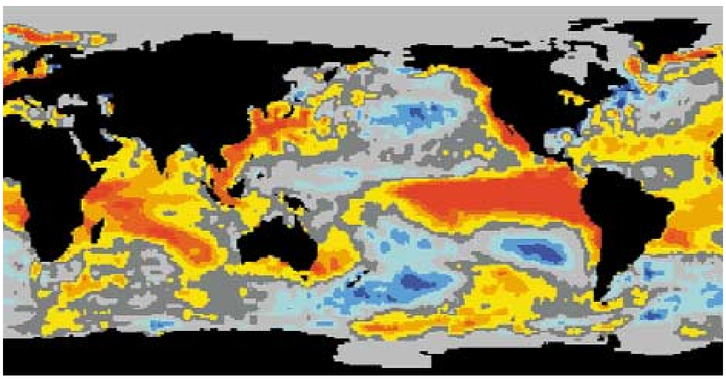
Above: At the Atmospheric Baseline Monitoring Station at Cape Grim in north-west Tasmania, CSIRO researchers have been tracking trends in the concentration of chlorofluorocarbon (CFC) and halon gases in the lower atmosphere. These long-lived, man-made gases are now known to catalyse the destruction of ozone in the stratosphere, which normally intercepts much of the damaging ultraviolet-B radiation reaching the Earth's surface.

The rate of increase in CFCs is declining, confirming the effectiveness of urgent measures taken under the 1988 Montreal protocol to reduce the influx of CFCs into the atmosphere. But bromine-containing halon gases continue to rise at a rate that will slow the recovery of the so-called 'ozone hole', a region of intense ozone depletion that appears over Antarctica each southern spring.

Below: CSIRO has the world's only collection of preserved, pristine air. The samples are taken at Cape Grim and date back to 1978. They are invaluable for assessing how levels of greenhouse and ozone-depleting gases have changed in the air during the past 20 years.



Global anomalies in sea-surface temperatures for January, 1998. Computers and remote-sensing satellites have transformed our understanding of sea-surface changes that modulate Australia's climate.



QDNR Drought Research Unit

it is not yet possible to predict impacts at a regional or local scale – precisely where the information is most urgently needed.

In 1975, another revolution was dawning: gene technology. Its impact on science has been as profound as that of the computer, although its commercial application is still in its infancy. Gene technology has revolutionised biological and medical research, and will transform agriculture in the coming decades, with the environment being a major beneficiary.

Researchers at the Division of Plant Industry cloned one of the world's first functional plant genes in 1983: a gene that protects maize against the effects of oxygen deprivation in waterlogged soils.

Geneticists can now study the most intimate details of how living organisms are organised, how they function, and how they interact with their environment. Recombinant DNA technology now allows plant and animal geneticists to transfer genes between unrelated species, to custom-design genes for specific purposes, or to modify an organism's existing genetic blueprint by 'tweaking' specific genes, or by turning off others.

By making precise genetic changes to familiar, well-adapted organisms, they can increase their productivity, enhance their nutritional qualities, their resistance to diseases and pests, or reduce their impact on the environment.

CSIRO researchers are modifying naturally occurring viruses that infect insects that damage crops, to increase their virulence. In a recent experiment they transferred the genetic blueprint of a simple insect virus into a plant, so that the virus is produced directly in the plant's leaves, where it will protect it against leaf-chewing larvae.

A gene isolated from the microbe *Bacillus thuringiensis* protects much of Australia's cotton crop against insect attack. The so-called Bt gene, which is activated with sunlight falls upon the plants' leaves, encodes an insecticidal protein that selectively kills *Helicoverpa* caterpillars and other leaf-chewing pests.

The Bt gene leaves no long-lived environmental residues, so poses no threat to non-target species such as earthworms, frogs, fish, birds and mammals. It has reduced the use of toxic, broad-spectrum insecticides.

New research has shown that plant genes that confer resistance against viral, bacterial and fungal infections, as well as against insect attack, all work by a very similar mechanism: the function as burglar alarms that sense the invader, and activate the plant's defensive mechanisms. The discovery opens the way for plant geneticists to import resistance genes from distant relatives of crop species, or to designing entirely new resistance genes. Like Bt-protected cotton, resistant crops would be more productive, and would reduce the use of environmentally damaging pesticides.

Enabling reparation

Ecos has reported on research into the litany of environmental problems that afflict Australia: rising water tables and salinisation of agricultural land, soil acidification, erosion, desertification, weed invasions, nutrient-induced eutrophication and toxic algal blooms in Australia's rivers and waterways.

Research has revealed the magnitude of these problems and their origins, and produced potential – or actual – solutions. Only a massive revegetation program can restore the hydrological balance of salt-affected agricultural lands across the continent. Australians must use water more wisely and sparingly, and reserve enough for the timely release of so-called 'environmental flows' in rivers and waterways to restore their health and biodiversity.

CSIRO found a highly effective biological control agent for the world's worst aquatic weed, *Salvinia molesta* – a tiny Brazilian weevil. After eradicating its own salvinia infestations, it offered the weevil to tropical nations in Asia and Africa, and today, salvinia has been controlled virtually everywhere in the world.

Australia's folkloric insect pest, the bushfly, is no longer the pest it was. Dung beetles imported by CSIRO from Africa and the Mediterranean region of Europe have successfully established in a range of environments throughout Australia. They inhibit fly breeding and enrich pasture soils by busily burying fresh cattle dung.

Chance for a power shift

Ecos has also offered its readers numerous examples of the virtues of basic research, of scientific serendipity, and of the ingenuity and persistence of scientists. One story, in

Blooms of blue-green algae, a consequence of increased nutrient levels in Australian waterways. Research has revealed the magnitude and origins of these and other environmental problems, and in some cases provided the basis of their solution.

particular, embodies all these elements: the story of partially stabilised zirconia (PSZ).

In the 1970s, researchers at the former Division of Tribophysics were given a zirconia die that had been used to extrude and shape hot steel – it possessed some mysterious quality that had increased its lifetime at least tenfold. The researchers found way the unusual composition of the die, and the way it had been processed and fired, had imbued it with extreme toughness and resistance to cracking in the face of physical shocks, and an ability to tolerate sudden temperature changes without shattering.

In 1976 the international journal *Nature* hailed transformation-toughened PSZ as the first 'ceramic steel'. But through the 1980s, PSZ failed to achieve the commercial potential promised by its extraordinary physical properties.

It seems PSZ was only awaiting the right opportunity. In the late 1980s, CSIRO researchers began experimenting with very thin sheets of PSZ as an electrolyte for a new-generation, solid-oxide fuel cell.

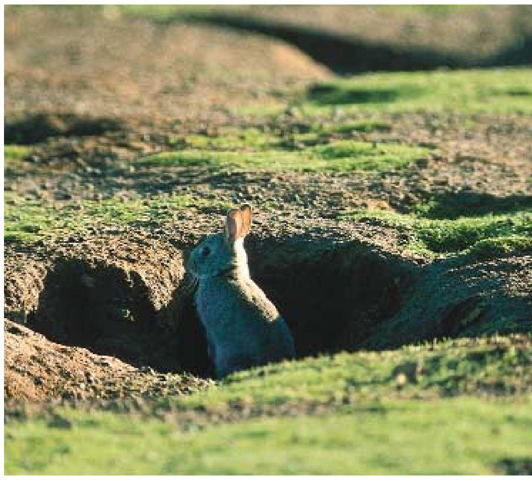
When a gas such as hydrogen or methane is passed at high temperature on one side (the anode) of a thin, impermeable membrane of PSZ, charged oxygen ions from air being passed on the other side (the cathode) migrate through the solid structure of the ceramic electrolyte itself. Their movement induces an electrical current in a circuit connected between the anode and the cathode.

A solid-oxide fuel cell generates electricity directly through this solid-state reaction, and the hot exhaust gases from combustion can be used to provide heat or to drive a gas or steam turbine. This dual action yields energy efficiencies of up to 80%, measured in terms of the amount of chemical energy in the fuel that ends up as electrical plus heat energy. Ceramic fuel cells are almost twice as efficient as the best diesel or coal-fired generators. This fuel efficiency, combined with the relatively low emissions of carbon dioxide from hydrocarbon fuels such as natural gas, could revolutionise the power industry next century.

Fuel cells are modular and can be stacked for higher energy outputs. Ceramic Fuel Cells Limited (CFCL) has recently demonstrated a five-kilowatt ceramic fuel cell 'stack', and is on track to produce a 25 kW prototype unit for field demonstration next year. Ceramic fuel cell stacks can be scaled up and installed wherever gas or LPG is available as a fuel, avoiding the heat-energy losses involved when electricity is transmitted long distances through high-voltage power lines.

CFCL is a world leader in the development of ceramic fuel cell technology. Its widespread adoption next century would benefit the environment by reducing the flux of greenhouse gases into the atmosphere from conventional oil and coal-fired power stations.

It could play a key role in helping Australia meet its obligations, under the Kyoto protocol, to cut its greenhouse-gas emissions, which are among the highest, per capita, in the world.



In the early 1990s, CSIRO began experimenting with a virus to control rabbits, which despite the historic success of the myxoma virus, released in the early 1950s, still cause enormous environmental damage and economic loss in Australia.
After its accidental escape in 1996 from Wardang Island, in South Australia's Spencer Gulf, rabbit calicivirus reached the mainland and spread rapidly across the arid and semi-arid zones, decimating rabbit populations. In its wake, ecosystems underwent a dramatic recovery – native plants not seen for decades germinated from seeds or re-sprouted from roots that persisted below ground.
By the time *Ecos* reaches 200, Australia could be using gene technology to control rabbits, along with other vertebrate pests such as the house mouse, and predators such as the fox and feral cat.
CSIRO researchers, with colleagues from universities and state conservation agencies, are developing a technique called immunocontraception as a generic weapon against vertebrate pests. It will employ genetically modified viruses, or edible baits containing transgenic bacteria, to produce non-lethal infections in pest species. The transgenic microbes will carry genes for antigens that will induce the infected animal's own immune system to destroy its own eggs or sperm, resulting in infertility.

Left: The Ceramic Fuel Cells Limited facility in Melbourne. The widespread adoption of fuel cell technology would reduce greenhouse gas emissions.