rested before they walked on the lunar surface. And they basically said, 'Well, hey: we've just landed on the Moon, pretty excited, can't sleep, want to start exploring as soon as possible.'"

The astronauts left the module three and a half hours earlier than expected. "What that meant for Parkes was that the Moon hadn't risen in their local sky yet. They had to wait about ten minutes for the Moon to get in their dish's beam path to get a good signal. And Neil wasn't going to just hang on the ladder waiting for that to happen."

The Moon had risen high enough for the station at Tidbinbilla, which would normally have taken over. Except there was another issue.

"We constantly get visits from people who don't believe we landed on the Moon."

Twenty-four hours earlier, a fire had damaged Tidbinbilla's electrical system. Although technicians worked around the clock to return the antenna to working order, NASA had already swapped to its back-up plan. "So Neil's coming down the ladder. NASA looks to Goldstone: upside-down picture, highly contrasted, no good. Parkes: no picture at all … That left Honeysuckle Creek."

The station there, the smallest of all the Apollo mission telescopes, was only meant to get voice and data transmissions from the lunar module. "But on that afternoon they were also carrying the TV signal. And they had a great picture. So NASA flicked the switch just in time, and 600 million people around the world could witness Neil Armstrong coming down the ladder, putting his left foot on the Moon and saying those immortal words: 'That's one small step for man, one giant leap for mankind.'"

After about eight minutes, the Moon was high enough for the more powerful Parkes telescope to take over.

"[*The Dish*] doesn't depict all that back and forth. And obviously it couldn't: it'd be five hours long with a cast of hundreds," Nagle says with a laugh. "And it's a great film, and it made people remember that Australia plays a role in these missions."

There's a tangible artefact at the CDSCC visitor centre: a 13-gram piece of moon rock (volcanic basalt), donated by NASA in 1994 in gratitude for Australia's participation in the Apollo missions. If you were hoping that this physical evidence, not to mention the remarkable story of DSS-46, would convince Moon landing sceptics that Apollo was not filmed on a Hollywood sound stage … "We get them all the time!" Nagle sighs. "We constantly get visits from people who don't believe we landed on the Moon. And it begs the question, 'Then why are you *here*?'"

CDSCC, in the wake of the Cassini mission, has plenty to get on with. For one thing, it's still the premier site for communicating with the 35 space missions currently operating.

"It's only going to get busier," Nagle explains. "Now Juno [Jupiter orbiter] is the main mission, and it's likely to get a extension; we've got the Martian seismological study InSight launching; we've got the James Webb Space Telescope heading on out there; and we're gearing up for Exploration Mission-1, the space launch system that will eventually take humans to the Moon and Mars – and next year is the Solar Probe Plus launch."

Then, in 2020–21, "we'll have five, maybe six missions arriving at Mars all within a one- or two-month period: NASA, the Europeans, the United Arab Emirates, Japan, possibly India and possibly [Elon Musk's] SpaceX as well".

So CDSCC will have a lot of priority-juggling ahead? "Yes, but we're good at what we do." **M**

The Great Southern Reef

BY **James Bradley**

Anybody who dives or snorkels along the southern Australian coast will be familiar with the kelp beds that line that part of the continent. Winkled into the topography of the sea floor, they are often things of beauty, fish darting in and out as the dark brown and honey gold fronds shift in the current. But even when the water is more turbulent, and the massing weight of the kelp sucks and pulls, they are majestic, the strength of their grip upon the rock impressive.

These kelp beds provide the ecological foundation of a string of temperate rocky reefs that follow the coast from Kalbarri in the west, across the Great Australian Bight to Victoria and Tasmania, and north again to Byron Bay. Dense with diverse and endemic life (in some places, as many as 80% of species are found nowhere else), these environments span 71,000 square kilometres and are economically significant, generating as much as $10 billion annually, primarily through fishing and tourism.

Until recently, these reef ecosystems have been studied and managed mostly in isolation from one another. This is partly an accident of history – a reflection of our state-based system of fishery regulation – but it's also a

reflection of our limited understanding of these habitats, especially those fringing the sparsely populated coasts of South Australia and Western Australia. In a paper published in 2016, a team of scientists led by marine biologists Scott Bennett and Thomas Wernberg argued that this was a mistake, and that these reefs are in fact one vast system stretching from one side of the continent to the other. A Great Southern Reef to match the Great Barrier Reef to the north.

Although it has yet to find broad recognition, it is a powerful and revelatory idea – recognising not just the interconnectedness and interdependence of these ecosystems but also kelp's role as the reef's foundation species.

The motivation behind Bennett and Wernberg's proposal isn't purely scientific. Instead, it reflects their frustration with the lack of public understanding of the challenges facing many of Australia's marine ecosystems. While the Great Southern Reef has yet to experience anything as catastrophic as the recent bleaching of the Great Barrier Reef, Wernberg argues its situation is no less critical, pointing to events such as the 2011 "marine heatwave" off Western Australia, an occurrence of unprecedented warm sea surface temperatures that wiped out kelp beds along more than 100 kilometres of coast, causing mass die-offs of many fish, shellfish and crustacean species.

The kelp beds lost in the 2011 heatwave seem unlikely to recover, and Wernberg argues that this is only the most visible instance of a much larger problem. We have also lost "seaweed in Sydney, kelp around Tasmania and kelp forests in the South Australian gulfs".

With the reef's biological engine gone, the ecosystem quickly collapses, the kelp replaced by algae, endemic species by the invaders.

Nor is the problem confined to the Great Southern Reef. "In the past two years alone we've seen more than 1000 kilometres of mangroves die in the Northern Territory, we've had many, many square kilometres of sea grasses lost in Shark Bay in Western Australia, yet none of it receives the same attention as the Great Barrier Reef. The only difference is perceptual."

Unsurprisingly, the most significant pressure upon the Great Southern Reef is climate change. Yet, while warming water can adversely affect kelp, the relationship is not as direct as it is with corals, which simply die when water temperatures rise beyond a certain level. Warming water allows herbivorous tropical species to move south, where, unconstrained by natural predators, they quickly devour the kelp. With the reef's biological engine gone, the ecosystem quickly collapses, the kelp replaced by algae, endemic species by the invaders.

Adriana Vergés, a marine ecologist at the University of New South Wales, has been studying this process of "tropicalisation". Like Wernberg, she argues that the pressures on kelp forests are significant and growing, pointing out that over the past decade the range and health of kelp forests in northern New South Wales have significantly diminished. In some areas, such as the Solitary Islands, off Coffs Harbour, kelp beds have disappeared entirely.

"The south-east of Australia is warming more than two times faster than the global average," Vergés says. "That's resulting in the rapid southward movement of many tropical and warm-water species."

Largely as a result of urchin grazing, 95% of the kelp forests around Tasmania are now gone.

This process has had its most devastating outcomes in Tasmania, where the giant kelp forests that encircled the island and filled its bays were once so dense they featured on shipping maps. In recent years, the East Australian Current has extended its reach, sweeping warm water down from the tropics. This has raised water temperatures around Tasmania by as much as 2.5 degrees Celsius, and allowed a host of species previously confined to mainland waters to migrate south.

The most significant of these is the long-spined sea urchin. A familiar sight along the eastern Australian coast, this marine animal is ruinously voracious, stripping areas of seaweed and other marine plants. Largely as a result of urchin grazing, 95% of the kelp forests around Tasmania are now gone. Together with overfishing, this has had a devastating effect on populations of both abalone and lobster.

Vergés argues that these developments pose a fundamental challenge to our approach to marine conservation. Where a traditional approach would aim to conserve and retain historical conditions, tropicalisation requires us to acknowledge both the inevitability of species moving beyond their traditional ranges and the emergence of new ecosystems as existing habitats are transformed. An emphasis on preserving the connectivity of the Great Southern Reef's component parts would give species greater capacity to respond to warming waters and to re-establish themselves after periods of loss.

Vergés points to research that shows that kelp forests in marine reserves have proved more resilient than those elsewhere, perhaps because predator species capable of controlling invading herbivores are more common in areas where fishing is restricted. In this regard, Vergés is particularly alarmed by the federal government's recent proposal to allow for expanded fishing and seafloor trawling in marine protected areas.

Wernberg accepts that rising water temperatures is a "trend that only seems to run one way". Yet he argues that because so many of the problems faced by the Great Southern Reef depend upon the interaction between warming water and local factors, in many instances its capacity to withstand climate change can be strengthened by limiting other stressors such as run-off, pollution and overfishing.

These are small slivers of hope. But while there is evidence some seaweed beds can be re-established, many of the losses experienced to date are likely to be permanent. And, more ominously, Australia's geography means there is only so far that the Great Southern Reef can contract southwards before we start seeing local, and possibly global, extinction events. "One of the reasons we coined the term Great Southern Reef," Wernberg says, "[is] to get people to focus on the fact we have a truly unique ecosystem here. We tend to forget that." M