NEWS FEATURE

MARIA STENZEL

Submersible pilots from the University of Ghent in Belgium find invading crustaceans at Antarctica's Palmer Deep in 2010.

TROUBLE BARES ITS CLAWS

Crabs invading the Antarctic continental shelf could deal a crushing blow to a rare ecosystem.

BY DOUGLAS FOX

On a dim February evening, seven people crowded around a row of television monitors in a shack on the rear deck of the RV *Nathaniel B. Palmer*. The research icebreaker was idling 30 kilometres off the coast of Antarctica with a cable as thick as an adult's wrist dangling over the stern. At the end of that cable, on the continental shelf 1,400 metres down, a remote-operated vehicle (ROV) skimmed across the sea floor, surveying a barren, grey mudscape. The eerie picture of desolation, piped back to the television monitors, was the precursor to an unwelcome discovery.

The ROV had visited 11 different sea-floor locations during this 57-day research cruise along the Antarctic Peninsula in 2010. Each time, it had found plenty of life, mostly invertebrates: sea lilies waving in the currents; brittlestars with their skinny, sawtoothed arms; and sea pigs, a type of sea cucumber that lumbers along the sea floor on water-inflated legs. But at this spot, they were all absent. After 15 minutes, the reason became clear: a red-shelled crab, spidery and with a leg-span as wide as a chessboard, scuttled into view of the ROV's cameras. It probed the mud methodically — right claw, left claw, right claw — looking for worms or shellfish. Another crab soon appeared, followed by another and another. The crowded shack erupted into chatter. "They're natural invaders," murmured Craig Smith, a marine ecologist from the University of Hawaii at Manoa. "They're coming in with the warmer water."

Cold temperatures have kept crabs out of

Antarctic seas for 30 million years. But warm water from the ocean depths is now intruding onto the continental shelf, and seems to be changing the delicate ecological balance. An analysis[1] by Smith and his colleagues suggests that 1.5 million crabs already inhabit Palmer Deep, the sea-floor valley that the ROV was exploring that night (see 'A warming welcome'). And native organisms have few ways of defending themselves. "There are no hard-shell-crushing predators in Antarctica," says Smith. "When these come in they're going to wipe out a whole bunch of endemic species."

Researchers are worried that rising crab populations and other effects of the warming waters could irrevocably change a sea-floor ecosystem that resembles no other on Earth. Scientists are racing to document these effects, even as they continue to explore this little-understood region. "This could have a really major reorganizing impact on these unique and endemic marine communities," says Richard Aronson, a marine biologist at the Florida Institute of Technology in Melbourne, who was part of a team that found crabs on another part of Antarctica's continental shelf in December 2010 (ref. 2). "It's a fascinating thing," he says. "A little scary, because it's a very obvious footprint of climate change."

CUT OFF BY COLD

Aronson has worried about the fragility of life on the Antarctic shelf for more than a decade. He spent December 1994 collecting fossils from Seymour Island, on the northeast fringe of the Antarctic Peninsula. The island's bare, crumbling hills contain the remnants of an ancient sea floor. In 200 metres of layered rock and fossils exposed by wind erosion, Aronson saw evidence of the most pivotal event in Antarctica's history: the continent's final separation from South America, starting around 40 million years ago. This event allowed the emergence of the circumpolar ocean current, which isolated Antarctica from warmer air and water masses farther north, and plunged it into perpetual winter. Aronson and his students analysed 10,000 fossils from before and after that sudden cooling, and a striking pattern emerged.

As temperatures fell, the sea floor bloomed with soft-bodied echinoderms — invertebrates including starfish, brittlestars, sea lilies and sea cucumbers. At the same time, crush wounds caused by crabs or sharks on the arms of fossil starfish and sea lilies became rare — evidence that these predators were declining[3].

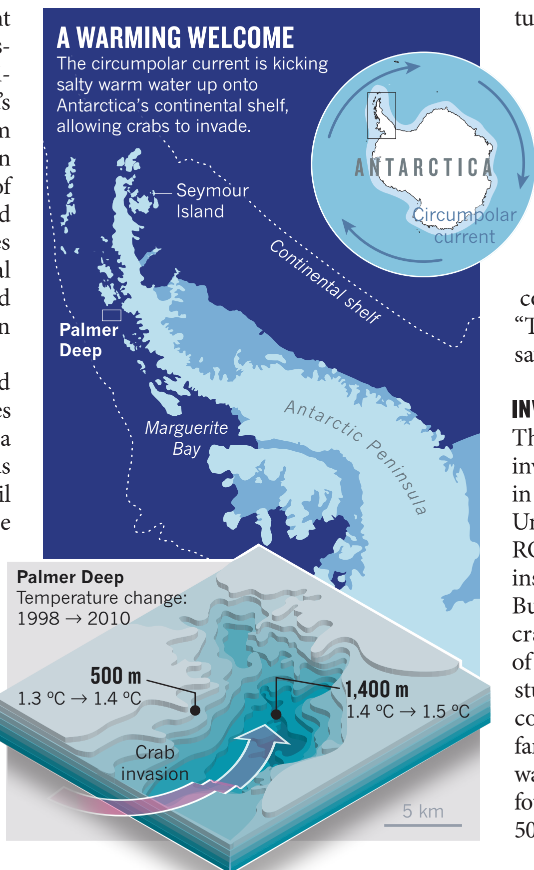
Crabs and lobsters were probably excluded by a physiological quirk. At temperatures below about 1 °C, they become unable to regulate magnesium in body fluids, leading to narcosis, clumsiness and paralysis of breathing. Most of the 100 or so fish species currently found on the Antarctic shelf belong to a single sub-order, whose members evolved antifreeze proteins to keep their blood flowing at subzero temperatures and then diversified to fill most niches in the frigid seas. They lack powerful jaws[4].

The result is an ecosystem reminiscent of that 350 million years ago, in which the top predators are slow-moving invertebrates such as starfish, sea spiders and ribbon worms[4]. "All of this stuff has got a very Palaeozoic flavour to it," says Aronson. The relaxation of natural selection allowed species to lose their natural armour, says James McClintock, a marine biologist at the University of Alabama at Birmingham. Animals on the Antarctic sea floor "are very weakly skeletonized", he says. "You can pick up an Antarctic clam and crush it in your hand."

By the mid 2000s, Aronson began to believe that if Antarctica's oceans warmed up, the ecological cascade that caused this blast-from-the-past ecosystem to flourish would run in reverse: crushing predators would return and wreak havoc[4]. That prediction is now being tested.

Westerly winds are strengthening and the circumpolar current is intensifying, driven by atmospheric warming and a hole in the ozone layer over Antarctica. These changes are lifting warm, dense, salty water from 4,000 metres down in the Southern Ocean up over the lip of the continental shelf.

Douglas Martinson, an oceanographer at the Lamont–Doherty Earth Observatory in Palisades, New York, has documented this process on the western side of the Antarctic Peninsula, where crabs are invading. Martinson installed five temperature and current sensors around Marguerite Trough — a deep canyon carved into the sea floor by glaciers advancing to the edge of the continental shelf in past ice ages. The moorings captured an insidious process: as the circumpolar current skirts Antarctica's continental shelf, it runs head-on into the steep wall of the trough. About once a week, a swirling eddy containing 100 cubic kilometres of warm water wafts up from that collision, spilling onto the continental shelf[5,6]. The same thing happens elsewhere, says Martinson: "It looks like this is what happens at all of the canyons that cut across the shelf."



A WARMING WELCOME
The circumpolar current is kicking salty warm water up onto Antarctica's continental shelf, allowing crabs to invade.

The temperature of this intruding water is only about 1.8 °C — but for an ocean region generally between 1 and –2 °C, the impact is substantial. And the incursion seems to have begun only recently, says Eugene Domack, a marine geologist at Hamilton College in Clinton, New York, who led the 2010 cruise to Palmer Deep.

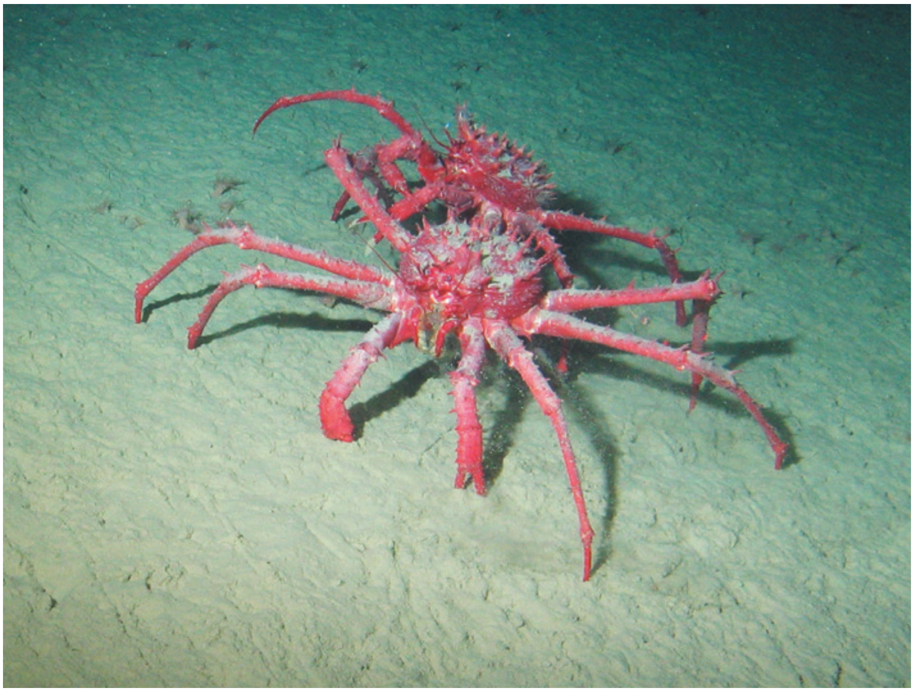
Domack has managed to date[7] the onset by measuring the amount of radioactive carbon-14 in deep-sea corals collected from the continental shelf — a process similar to reading tree rings. The corals had grown for 400 years before being dredged up. The carbon-14 content increased smoothly along the coral's growth axis for the first 350 years, and then dropped suddenly — indicating that the coral was being bathed in water with a reduced carbon-14 content. The water from the depths of the circumpolar current would fit the bill: it has been isolated from the carbon in the atmosphere for centuries. On the basis of these measurements, Domack has deduced that the warm-water incursion "kicked in somewhere around the turn of the last century, 1920 or 1930".

According to Domack's results, the incursion seems to have started following the end of the Little Ice Age — a period of relative cold that began in the Middle Ages — but it has intensified as anthropogenic warming and southern ozone depletion have taken hold. Average water temperatures west of the Antarctic Peninsula have risen by 1 °C in the past 50 years, and continue to rise by 0.01–0.02 °C per year[1,6]. "The heat injection is going through the roof," says Martinson. "It's going up exponentially."

INVASIVE SPECIES

The first evidence that crabs were poised to invade along with the warm water came early in 2007. Sven Thatje, a marine ecologist at the University of Southampton, UK, launched an ROV to the outer slope of the Antarctic Peninsula to map glacial grooves on the sea floor. But its cameras also caught sight of 13 king crabs (*Paralomis birsteini*) between depths of 1,300 and 1,100 metres (ref. 8). Thatje had studied the cold tolerance of these crabs and concluded that they could probably survive farther north at 2,000–4,000 metres, where the water is a degree or two warmer — "but then we found them even on the continental slope" only 500 metres below the shelf itself, he says. "These

KATRIEN HEIRMAN



King crabs (*Neolithodes yaldwyni*) are invading Antarctic seas, where they prey on local species.

crabs were thriving at 1 °C. They were basically at the physiological limit that I had anticipated."

But it was Smith's discovery of *Neolithodes yaldwyni* king crabs in Palmer Deep, 120 kilometres in from the edge of the continental shelf, that demonstrated a true invasion. West of the Antarctic Peninsula, cold water sits on top of warmer water. To reach Palmer Deep from the outer ocean, crabs or larvae must have crossed what amounts to a cold, high mountain pass only 450 metres below sea level before settling into Palmer Deep, at depths of 800–1,400 metres (ref. 1).

In December 2010, Thatje, working with Aronson and McClintock, returned to Antarctica and towed a submersible up and down the continental slope near the mouth of Marguerite Trough. The ROV traced 100 kilometres of sea floor, capturing 150,000 photographs that revealed hundreds of *P. birsteini* crabs between 2,300 and 830 metres down[2]. "If you extrapolate," says McClintock, "we're talking about millions of crabs."

The crab invasion could have started a decade or two ago. When Smith re-examined photographs taken at the bottom of Palmer Deep in 1998, he saw telltale claw marks in the mud — indicating that at least some crabs were already present, even if none had been caught on camera[1]. Domack looked at 30 years of water-temperature data measured at Palmer Deep during earlier cruises, and found that the sea-floor valley had gradually warmed[1] — becoming ever-more hospitable to the crabs. Smith is now comparing gene sequences from crabs sampled in Palmer Deep with ones collected from deeper, warmer waters farther north in the Southern Ocean. The data from these experiments should help him to zero in on the crabs' origins and the date of their arrival.

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For a slideshow of crabs and the species they threaten, see: go.nature.com/xbbdml

But even without knowing the exact history of the invasion, the implications seem clear. Animals living on the edge of their physiological limits often struggle to survive and reproduce, but 19 out of 27 crabs that Smith collected during a cruise in 2011 turned out to be females carrying larvae or eggs. "This population is reproducing like crazy," he says. "It's probably here to stay and expand." As the ceiling of cold water continues to lift over the next 10 or 20 years, crabs could spill out of Palmer Deep and Marguerite Trough — and colonize the broader continental shelf at depths of 400–600 metres, devastating the endemic sea life.

STIFLING HEAT

The warm waters will also bring other perils for Antarctica's sea-floor gardens. Many of the species here are exquisitely sensitive to increases in temperature. The brittlestars and other invertebrates have extremely slow metabolisms — an adaptation to the cold water — and only meagre ability to absorb and transport oxygen. "So what do those guys do if it warms up and their metabolic rate speeds up?" asks Lloyd Peck, a biologist at the British Antarctic Survey in Cambridge, who has monitored these creatures in aquarium warming experiments. Their oxygen demand revs beyond what their gills can supply — and they slowly suffocate[9,10].

About half of the two dozen Antarctic species that Peck has studied seem to do fine in water 2 °C warmer than current maximum summer temperatures — but the rest seem to suffer. "At least two of the species that we think are going to be the first [to disappear] could give problems for the balance of the ecosystem," he says. Those are the Antarctic clam (*Laternula elliptica*)[9] and the shallow-water brittlestar (*Ophionotus victoriae*)[10], both mainstay species that eat dead plankton and other organic trash that falls from above, and turn it into the biomass that feeds everything else on the sea floor. But these species either die or become dangerously sluggish at even 1 °C above current summer highs — temperatures that could become widespread in 50–100 years.

If rising temperatures cause brittlestars and clams to disappear, then more falling detritus might be consumed by microbes instead of being converted into edible biomass — meaning that it would sustain fewer animals, overall, on the sea floor. Alternatively, filter-feeding sponges might multiply to fill the niche. Either way, the mix of species supported further up the food chain might no longer include large numbers of archaic predators such as starfish, ribbon worms and sea spiders.

Julian Gutt, a marine ecologist at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, admires Smith's work with the crabs, but withholds final judgement on whether the crustaceans are a new piece of this destructive puzzle, or a long-present fixture. Repeat surveys showing that the crabs are expanding their foothold over time would confirm an invasion, he says. But "if they move into new habitat, some serious impact is quite likely".

Aronson, for one, will be watching closely for signs that this is happening. And in his experience, optimism is not warranted. "Every time we make a prediction of what we think will happen in the next 50 years, then poof, 10 years later, there it is," he says. "So I think this is going to be happening more rapidly than, as conservative scientists, we're used to predicting." ■

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