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ESSAYS

James Bradley

The end of the oceans

Vanitas of the Anthropocene. Plastic waste and the remains of coastal wildlife, Swansea Bay, Wales. Series by Jasmine Färling

The world's oceans and all marine life are on the brink of total collapse

In June this year, scientists from the University of Tasmania and the University of Technology Sydney published research showing that over the past decade the biomass of large fish in Australian waters has declined by more than a third. The results may have jarred with government claims of Australian fisheries being among the most sustainable in the world, but they closely matched official figures showing a 32 per cent decline in Australian fishery catches in the same period. The declines were sharpest in species targeted for fishing and areas in which fishing is permitted, but even populations of species not exploited by fishing declined across the same period.

The notion that a third of large fish in Australian waters disappeared in just 10 years should be of profound concern to all. The health of marine food webs depends upon healthy populations of the predator species that regulate populations of smaller species; declines in their numbers are likely to lead to hastening disruption of ocean ecosystems.

Even more disturbingly, these falls mirror similar declines in marine life around the world. According to a 2015 report by the World Wildlife Fund for Nature, populations of marine vertebrates including fish, turtles, birds, whales, dolphins and seals fell by half between 1970 and 2010. And although the drops in numbers were most extreme during the 1970s and early 1980s, in recent years they have accelerated again, suggesting a similar study conducted today would find an even greater decline. And in a separate study the United Nations found that, although demand for fish is still rising, almost 90 per cent of the world's fisheries are fully fished or overfished.

There is no question these headline figures disguise considerable variation between species and regions. (The study of Australian fisheries found the biomass of exploited species actually increased in areas where they were protected from fishing.) But that should not divert our attention from the fact that declines were worst in those species humans rely upon for food: the WWF study found populations of tuna, mackerel and bonito dropped by 74 per cent in the same period. Or that other studies estimate the populations of large species such as whales, dolphins, sharks, seals, rays and turtles have declined by more than 75 per cent on average, with some species, such as right whales, leatherback turtles and blue whales, declining by 90 per cent or more.

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Half of all marine vertebrates gone in 40 years. A third of large fish in Australian waters gone in the past decade. Ninety per cent of the world's fisheries already at their limits or beyond. These figures speak to a reality few want to acknowledge, and the decline is made even more shocking by the fact that it has taken place so rapidly. As Eelco Rohling, professor of ocean and climate change at the Australian National University, points out, although there is evidence that hominids were travelling by boat more than 50,000 years ago, and middens and other archaeological evidence make it clear we have relied upon the ocean for even longer, marine environments remained largely pristine until fewer than 500 years ago. In fact, they only really began changing in the early 1800s. "While we were still sailing around in wooden ships powered by the wind, humans didn't really have much of an influence. The real change comes with industrialisation, and the power to move ourselves around with steam and other technologies. Once that happens, you begin to see mass whaling and fishing on scales that were unimaginable beforehand."

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BY **James Bradley**

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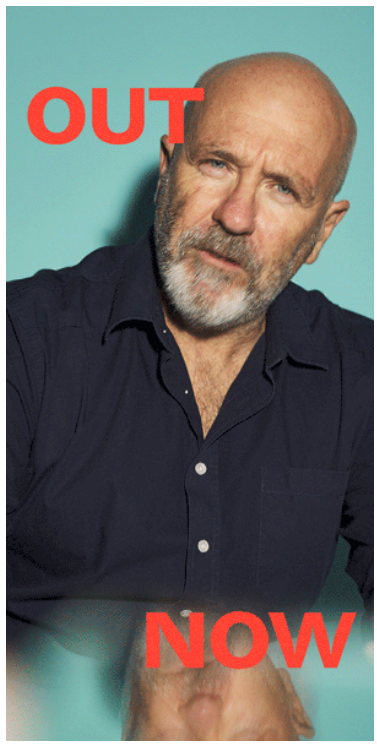

It is difficult for us to imagine the oceans before humans transformed them, and how they teemed with life. In Anna Clark's history of fishing in Australia, *The Catch*, she describes the "fishing Eden" that greeted early Europeans: "the sea floor off the west coast of Tasmania carpeted red with crayfish; fish so thick that nets could be set at any time of the day; an 'astonishing magnitude' of Australian salmon; and mountains of mullet that migrated annually up the east coast". This accords with James Cook's and Joseph Banks' descriptions of the density of marine life they found in Botany Bay, where the crew speared stingrays weighing as much as 152 kilograms and reported catching "about 300 pounds weight of fish" in just "3 or 4 hauls" of the net. In Tasmania, whales congregated in the Derwent River in such numbers they were a hazard to shipping, while on the other side of the globe, off the coast of Cornwall, a shoal of sardines was spotted in 1836 that stretched for well over 100 kilometres. Today there are approximately 90,000 nesting female green turtles left worldwide, but studies suggest that when Europeans arrived in the Americas there were more than 50 million in the Caribbean alone. Reports describe them filling the ocean from horizon to horizon as they grazed upon the seagrass that surrounded the Cayman Islands; as late as the 18th century, ships en route to the Caymans could navigate through darkness by the sound of the turtles' shells knocking together as they fed. Further back again the Roman writer Oppian describes a Mediterranean so full of fish it was possible to catch tuna by simply dropping a log with a spike on it into the water.

More often than not, these descriptions of astonishing abundance were merely the prelude to their destruction. Despite Indigenous Australians having fished along coastlines for tens of thousands of years without adverse effect, Australian fisheries began to collapse within a few generations of European colonisation. The bays around Sydney were denuded of oysters by the 1860s; by 1880 Sydney Harbour, once brimming with fish, was described as "scarcely … a source of supply at all"; and by the 1920s stocks of Sydney's tiger flathead had collapsed due to the introduction of ocean trawling. The decline in numbers also brought reductions in size, as fish were caught and killed before they could reach adulthood: where once sturgeon up to 5 metres long were common in the bays and estuaries of North America, now they are gone, while the immense rays that glided across the sandy bottom of Botany Bay in Cook and Banks' time would be exceptional today. Even Oppian's teeming Mediterranean is now so devoid of fish that many marine biologists call it the Deaditerranean.

Yet for sheer focused ferocity, little compares to the carnage wrought upon marine mammals by whalers and sealers. Scientists estimate at least three million whales were wiped out in the 20th century alone, a massacre that peaked in the 1960s and killed more than two thirds of the global population of sperm whales and 90 per cent of blue whales, as well as bringing northern right whales (so known because their placid nature and tendency to float after death made them the "right" whale to kill) to the brink of extinction. Seals were also killed in the millions: in his classic book, *Sea of Slaughter*, Canadian writer Farley Mowat calculates at least 13 million seals were killed between 1830 and 1860 in Newfoundland alone, while in the early years of the 19th century populations of southern fur seals on subantarctic islands were reduced from between one and two million to a mere few hundred in just a few decades.

It is difficult not to recoil from these sorts of statistics. The violence and cruelty they speak to horrified even observers of the era, and in a time when we are increasingly aware that other animals think and feel and even grieve, the idea of this sort of slaughter is almost unbearable. Yet such exploitation is also only one symptom of a much larger crisis overtaking marine environments, a perfect storm of pressures that is altering the oceans in profound and often irreversible ways. The magnitude of this transformation is difficult to comprehend. Making sense of it demands we grapple with its terrifying scale and rapidity in geological terms. But, more deeply, it demands that we recognise not just the complexity and interconnectedness of the forces that shape life on Earth but also the degree to which we are all implicated in what is taking place.

Two hundred kilometres to the east of the Philippines, the ocean floor

drops vertiginously into the Mariana Trench, a vast crescent-shaped scar in the Earth's surface. More than 2500 kilometres long, and averaging some 70 kilometres in width, its deepest point, the Challenger Deep – a small, slot-shaped valley at its southern end – lies 11 kilometres beneath the surface. Testament to the violence of the forces that drive the Earth's drifting continental plates, it was once believed to be evidence for the now-discredited theory that the Pacific basin is the wound left when the Moon's matter was ripped free of the Earth by centrifugal force.

The depth of the Mariana Trench makes it impossibly hostile to surface-dwelling life. Water pressure is more than 1000 times that at sea level, and temperatures rarely rise above 4 degrees Celsius. Humans have been there only four times, yet in May of this year researchers from Japan's Global Oceanographic Data Center found a plastic bag at its bottom.

This bag has the dubious distinction of being the deepest known piece of plastic waste. Yet it is only one of the thousands of pieces of rubbish catalogued in the centre's Deep Sea Debris Database, which also includes fishing nets, tyres, washing machines, bottles, tins, sneakers … even a gym bag. Of these items, more than 33 per cent are plastic, and 89 per cent of those are single-use products such as plastic bottles and utensils, ratios that increase to 52 per cent and 92 per cent at depths of more than 6 kilometres.

Until recently, public concern about marine pollution was primarily focused on oil spills and their catastrophic effects on seabirds and coastal environments. These mostly used to come from tankers – 1989's *Exxon Valdez* disaster released more than 40 million litres of crude oil across 28,000 square kilometres of ocean and 2100 kilometres of coastline. But as demand has pushed global oil production ever higher and technology has allowed fossil-fuel companies to drill in waters that only a few decades ago would have been regarded as impossibly deep, the number of spills from pipelines and drilling has increased fourfold. This convergence of growing technological capability and increased risk underpins public resistance to recent attempts to open the relatively pristine waters of the Great Australian Bight to exploration and drilling.

As is often the case, though, this is only part of the story. While the short-term effects of oil spills are often catastrophic – the *Exxon Valdez* disaster killed hundreds of thousands of seabirds, thousands of otters, large numbers of seals, dolphins and orcas, and countless fish and invertebrates, as well as causing long-term damage to the area's ecosystems – the amount of oil released by spills is barely a third of the amount that enters marine environments as run-off from human activities on land, shipping discharges, and use of fossil fuels.

In recent years, however, concern about oil spills has been overtaken by growing alarm about the impact of plastic upon marine environments. Humans have produced 8.3 billion tonnes of plastic since mass production of it began in the early 1950s, a figure that continues to rise vertiginously year by year: a staggering 335 million metric tonnes is estimated to have been created in 2016 alone. Able to be produced so cheaply that recycling is rarely economic, most plastic ends up in incinerators and landfill. The rest leaks out into the environment, with at least 8 million tonnes a year washing into the oceans.

Jennifer Lavers, a marine biologist at the University of Tasmania, recently made the scale of the problem graphically clear. In 2015, Lavers and six others travelled to Henderson Island in the South Pacific to conduct preliminary work on a program to eradicate rats introduced by Polynesians almost a thousand years ago.

Henderson Island is roughly midway between New Zealand and South America. Save for the 50 people living on Pitcairn Island some 200 kilometres to the south-west, one must travel almost 700 kilometres west to the Gambier Islands before encountering human habitation. To the east there is nothing but Easter Island, almost 2000 kilometres away. Prior to this year Henderson was principally famous as a footnote to literary history: in 1820 Captain George Pollard and what was left of his crew made landfall on the island after their ship, the *Essex*, was rammed and sunk by a sperm whale; 30 years later their story would help inspire *Moby Dick*.

Lavers has been studying plastic pollution for much of her career. Yet what she saw when she arrived on Henderson Island shocked even her. “I know plastic is ubiquitous. It’s found from the Arctic to the Antarctic and everywhere in between, so I don’t go anywhere without expecting to find it. Yet every now and then I arrive somewhere I’m caught off guard. Henderson is one of the most remote islands in the world, it’s one of only a handful of raised coral atolls in the world, it’s World Heritage listed, it’s surrounded by one of the largest marine protected areas in the world. And yet there laid out in front of me was a concentration of plastic unlike anything I’d ever seen.”

Lavers and her team calculated there were 17.6 tonnes of plastic littering Henderson’s beaches with an average of more than 670 individual pieces per square metre. Of this, most was lying on the surface or buried in the first 10 centimetres of sand. And these amounts were increasing all the time: a survey of a 10-metre stretch of the island’s north beach found new pieces of plastic washing up every day. Yet as Lavers points out, the 17.6 tonnes of plastic she and her team found on Henderson constitutes less than two seconds of the annual global production of plastic, and only a tiny proportion of the estimated five trillion pieces of plastic believed to be floating in the ocean.

One does not have to look far for examples of the toll plastic exacts upon ocean wildlife: birds, fish, whales and other marine animals are all vulnerable to entanglement. Likewise, studies of turtles, seals, dolphins and birds suggest tens of thousands perish every year from swallowing plastics. On Midway Atoll, in the North Pacific, up to a third of albatross chicks die every year, many of them starving to death after being fed plastic refuse that their parents have mistaken for food. American photographer Chris Jordan’s images of their bedraggled corpses, rotting bellies distended with plastic caps and other refuse, provide a mutely eloquent testament to the effects of this process.

But plastics also pose a more insidious threat. Once adrift in the ocean they begin to break down, dissolving into what is known as microplastics, tiny fragments ranging in size from millimetres to nanometres. The highest concentrations of these microplastics are found in the oceans’ gyres: vast circulating currents created by the Earth’s rotation that act like huge vortices, drawing waterborne objects toward their centres.

The best known of these gyres is in the North Pacific, and at its centre lies the now-infamous Great Pacific Garbage Patch. Located midway between Hawaii and North America, the patch covers approximately 1.6 million square kilometres (or twice the size of New South Wales), with concentrations of plastic pollution reaching 100 kilograms per square kilometre at its centre. But while the Great Pacific Garbage Patch has received the most attention, it is not alone. As Lavers’ experience on Henderson demonstrates, high concentrations of plastic pollution are also to be found at the centre of the South Pacific gyre, as well as those in the North and South Atlantic, while new research by Lavers and others suggests the Indian Ocean gyre may actually be more polluted than the Pacific’s.

Along with the tiny beads of plastic deliberately added to products such as face scrubs and toothpaste, and the billions of tiny filaments produced by artificial fibres, these microplastics have invaded the ocean’s food chain, gathering in higher and higher concentrations as one moves upward through the layers of predation. In the eastern Pacific, microplastics are now ubiquitous in the host of species of tiny free-swimming or floating animals known as zooplankton. These creatures fill the oceans’ waters and act as a foundation of the oceans’ ecosystems. In some parts of the ocean there is now more plankton-sized plastic than plankton, meaning organisms that rely on plankton for food, such as whales, are consuming it in extremely large quantities.

The long-term effects of this are not yet well understood, but there is no doubt ocean microplastics are also being consumed by humans: studies have detected them in fresh and tinned fish, while a study published earlier this year found that mussels in Britain contained up to 700 pieces of microplastic per kilogram, and other studies have found them in both fish and sea salt, while a study in California found a fifth of fish in local markets contained fibres from artificial fabrics (one study found a single load of polyester or acrylic clothing can release more than half a million microfibres). Their prevalence is made even more disturbing by the growing evidence that microplastics absorb pollutants such as DDT from seawater, as well as organic molecules such as oestradiol, which is used for birth control. Other studies have found that microplastics contain high levels of chemicals that are known to disrupt the endocrine system and affect reproduction in many species.

Plastic pollution is far from the only form of oceanic pollution. Eelco Rohling from ANU, for instance, points to the largely unreported threat of polychlorinated biphenyls, or PCBs. Originally used in the 1920s for cooling and insulation, PCBs were quickly incorporated into paints, adhesives, the PVC coatings on electrical wires and many other products. While their widespread use meant large quantities were released into the environment, it was not until the mid 1960s that Sören Jensen, a Danish scientist looking for evidence of DDT in fish, found traces of PCBs in pike caught in Sweden. Over the next two years he found traces of them everywhere: in fish, in birds, even in the hair of his wife and daughter.

In the years since Jensen's discovery, PCBs have been banned or regulated in many countries. But PCBs have not gone away. Quite the opposite: studies show PCBs have permeated marine environments around the world, so much so that one recent study found high concentrations of them in the bodies of shrimp-like crustaceans called amphipods living almost 10 kilometres beneath the ocean's surface.

The presence of PCBs in the ocean is extremely concerning. Highly toxic in even small doses, they cause cancer, liver damage, reproductive problems and deformities in many species, including humans, as well as disturb hormonal balances in fish, birds and mammals, and cause neurological disorders in birds. Because they collect in fatty tissues they also become more concentrated as they move up the food chain, meaning they accumulate in the bodies of long-lived high-level predators such as sharks, seals and cetaceans.

The long-term effects of this are not yet fully understood, but they may well be significant: PCBs have already been implicated in mass die-offs of certain populations of dolphins, and are known to result in increased infant mortality in whales and dolphins, who transfer high concentrations of them to their young in their milk. Worse yet, PCBs break down extremely slowly when kept out of sunlight, meaning they can linger in the deep ocean and in the bodies of animals and fish for decades or even longer, their continued presence a reminder of the way the effects of our actions persist.

The threat posed by plastics, PCBs and other forms of marine pollution may be immense, but it pales into insignificance against that of climate change, something that was made heartbreakingly clear in 2016 and 2017, when the Great Barrier Reef suffered devastating back-to-back bleaching events that killed almost half of its coral.

Coral bleaching occurs when rising water temperatures cause coral polyps to expel the colourful algae they secrete in their bodies. Because the polyps – tiny animals that exist in a symbiotic relationship with the algae – rely upon the algae for food, bleached corals quickly starve or succumb to disease. With the coral gone, reef ecosystems collapse, the teeming communities of fish and other organisms giving way to the algae-coated skeletons of dead coral.

Only 40 years ago, coral bleaching was almost unknown. But in the 1980s researchers began to observe bleaching events on reefs in the Pacific and the Caribbean. At first these events were geographically confined and, in the Pacific at least, associated with the elevated sea temperatures produced by El Niño events. Then, in 1998, unusually warm waters triggered mass bleaching events on reefs around the globe, killing 16 per cent of the world's coral. The pattern was repeated when mass bleaching struck the Great Barrier Reef in 2002, but this time with a frightening new twist. Whereas the elevated sea temperatures of 1998 had been produced by the intense El Niño of 1997–98 compounding the background warming associated with climate change, in 2002 there was no El Niño: the water was just hot.

In the decade and a half since 2002, rising ocean temperatures have led to more frequent bleaching on reefs around the world. Yet the events of 2016 and 2017 were exceptional in both scale and severity, and suggested we have entered a new and critical phase in the transformation of marine environments. In previous bleaching events there tended to be what James Kerry, a researcher at the Australian Research Council Centre of Excellence for Coral Reef Studies at James Cook University and coordinator of the National Coral Bleaching Taskforce, calls "a spectrum of winners and losers", meaning some corals – mostly the less structurally complex varieties – fared better than others. But, in 2016 especially, temperatures were so high that even the really hardy corals became losers. Kerry explains that "we have categories we use to assess the level of bleaching, the highest of which is category four, which means 60 per cent or more of the coral is bleached. But after 2016 we really need a category five, for reefs that are 80 or 100 per cent bleached."

For Kerry and many other scientists who work on the Great Barrier Reef, the events of 2016 and 2017 were deeply upsetting. Describing his first sight of the damage, he hesitates. "We had one day in a helicopter when we flew for eight hours, and of the 500 reefs we surveyed only three weren't bleached, which meant you were flying for hundreds of kilometres and every reef you saw was white. That was really difficult."

This situation is being repeated around the world. In the Maldives, up to 90 per cent of reefs bleached in 2016 and 2017. Elsewhere in the Indian Ocean, reefs in Kenya, Sri Lanka and along Australia's west coast all suffered extensive damage, with up to 90 per cent of shallow-water corals affected. Reefs in the Caribbean have been badly damaged, losing up to 80 per cent of hard coral cover since the 1970s, while in Florida one survey found up to two thirds of coral had died.

For Ove Hoegh-Guldberg, professor of marine science at the University of Queensland and coordinating lead author on the oceans chapter of the Intergovernmental Panel on Climate Change's Fifth Assessment Report, the events of 2016 and 2017 were not a surprise. In 1999 Hoegh-Guldberg published a paper predicting the disappearance of most warm-water corals and the reefs they build by the middle of the century. At the time his predictions were dismissed as alarmist; today they look conservative. "We underestimated how quickly the changes would occur. Two decades ago we predicted back-to-back bleaching events by mid century. They're happening right now."

Given time, reefs can recover, recolonised from other reefs or deeper, cooler water. But this process is slow: even fast-growing corals require 10 to 15 years to regrow, while others can take decades. In a warming world, that is not time they are likely to get, as Kerry makes clear. "Year on year, there's a 30 per cent chance that each year will be hotter than the year before, so the chances of getting another bleaching event are very high. The chances that those corals will reach adulthood without experiencing a serious bleaching event is very low. That means the problem isn't that the reef doesn't have the capacity to regenerate, but that it will keep getting knocked down by these big events. Looking ahead, that's the most likely scenario."

Hoegh-Guldberg's assessment is even starker. Without decisive action on climate change he foresees bleaching events becoming an annual occurrence within a decade or two. "If we don't rapidly put the brakes on emissions, coral reefs as we know them will disappear by 2025 or 2030."

The coral reef might be the first marine ecosystem to suffer irreversible damage or collapse due to climate change, but it will not be the last. In many parts of the world, kelp beds, which underpin a range of temperate marine ecosystems, are retreating, driven towards the poles by the effects of warming waters. In Australia this process is already visible along the east coast: in northern New South Wales the range and health of kelp forests are already significantly diminished, while kelp beds off the Solitary Islands near Coffs Harbour have entirely disappeared. Similarly on the west coast, 100 kilometres of kelp beds disappeared in the aftermath of a marine heatwave in 2011. Yet nowhere have the effects of this process been felt more acutely than in Tasmania. Beds of giant kelp that were once so thick they had to be marked on shipping maps have all but disappeared, largely as a result of the arrival of the long-spined sea urchin, borne south from the mainland by warming waters.

Likewise in Antarctica, where upper ocean water temperatures have risen by more than 1 °C since 1950, new species such as the king crab (a ferocious predator previously confined to the deep ocean) are invading the ecosystems of the continental shelf.

Nor are warming waters the only threat associated with climate change. In 2013 the Intergovernmental Panel on Climate Change predicted sea-level rises of between 26 and 82 centimetres by the end of this century, but those figures look increasingly optimistic. In 2015 NASA research predicted sea-level rises of a metre or more over the next century or so, while a 2017 report from the US National Oceanic and Atmospheric Administration found that rises of 2 to 2.7 metres were plausible, particularly in light of the increasing instability of Antarctic ice sheets.

To say we are unprepared for this is an understatement. Sea-level rises of up to a metre or more within decades are now inevitable. And while these will significantly affect cities and communities in low-lying areas, they will also threaten the viability of a wide range of coastal and estuarine environments, in particular vitally important mangroves and seagrass beds, and place even greater pressure upon coral reefs. These effects will be amplified by the likelihood of more violent storms and larger waves.

Yet the most insidious and dangerous effect of climate change may lie elsewhere, in what Eelco Rohling calls the "silent killer" of ocean acidification. To appreciate the problem of ocean acidification it is necessary to understand that ocean chemistry and atmospheric chemistry are linked, and that the levels of gases in each are in equilibrium. As the concentration of carbon dioxide in the atmosphere rises, so too does the concentration of carbon dioxide dissolved in seawater.

Dissolving carbon dioxide in seawater causes a chemical reaction that produces carbonic acid and liberates hydrogen ions. This increases the acidity of the water (the "H" in the term pH refers to hydrogen) and, because some of these hydrogen ions also bind with carbonate and aragonite, also reduces the amount of these chemicals present in seawater.

This reaction is part of what is known as the marine carbon cycle. Inorganic carbon transferred from the atmosphere into the warmer surface layers of the oceans is absorbed by the actions of algae that photosynthesise it into organic carbon, and organisms such as shellfish, coral and plankton that combine it with carbonate and aragonite to create calcium-carbonate shells and skeletons. Upon the death of these organisms, much of the organic carbon and calcium carbonate they created is transferred to the colder deep ocean, where it either settles into sediment or is returned to the upper levels of the ocean through the processes of thermohaline exchange that drive the world's currents. Over the long time-scales of natural variability, these cycles regulate the pH of the ocean's waters, preventing significant change. But very rapid increases in carbon dioxide, such as those of recent decades, cannot be accommodated by these natural cycles, resulting in rising acidity.

Although the bulk of carbon dioxide has been produced since the 1960s, humans have been adding it to the atmosphere since the start of the industrial revolution. This has occurred either through the use of fossil fuels or by interfering with the planet's capacity to absorb the gas by clearing forests or draining natural carbon sinks like swamps and peat bogs. Of that extra carbon dioxide, somewhere around 30 per cent has been absorbed by the oceans, increasing their acidity and decreasing their average pH from 8.2 in pre-industrial times to 8.1 today. (Somewhat confusingly, an increase in acidity

corresponds to a decrease in pH.)

This might seem an insignificant amount, but pH is a logarithmic scale, where one unit equals a tenfold change, which means this drop of 0.1 corresponds to a 30 per cent change. And this process is expected to accelerate as the amount of carbon dioxide in the atmosphere continues to increase, reducing the pH of the oceans to 7.8 or 7.7 by the end of the century. Seawater is naturally slightly alkaline, so this sort of increase won't transform it into battery acid. Nonetheless this rate of change is terrifyingly fast in geological terms: a similar rate of change has not been recorded since the mass extinctions that accompanied the disappearance of the dinosaurs. Rapid acidification of the oceans was also at least partly responsible for the Permian-Triassic Extinction event that took place just over 250 million years ago. This was the single largest mass extinction in our planet's history, wiping out 90 per cent of all life on Earth and 95 per cent of life in the oceans.

Ocean acidification is likely to affect some marine animals directly. Research shows fish exposed to more acidic water develop a condition known as acidosis, affecting their growth, respiration and ability to reproduce. Other studies suggest more acidic waters interfere with a neurotransmitter that plays a crucial role in regulating a range of behaviours in a wide variety of organisms. Snails and crabs affected in this way become less able to make survival decisions or become confused when evading predators, while clownfish exhibit behaviours that suggest their sense of smell – crucial for their ability to avoid predators – is significantly impaired, making them prime candidates for extinction.

The increased energy required to absorb carbonate from more acidic water will also have serious consequences for molluscs, corals, crustaceans, and other marine organisms that use calcium carbonate to construct shells and other skeletal structures. As Eelco Rohling explains, "If an organism has to expend too much energy because the water is too acidic then the organism's shell will be incomplete or malformed or won't form at all, meaning the organism isn't viable. Larvae that have to produce carbonate to grow will find that particularly difficult, and many simply will not survive."

Studies simulating the effects of levels of acidity expected by the end of the century show many molluscs and crustaceans will decrease in size and become more vulnerable to predators and disease. These effects are already visible in some parts of the world, with acidifying waters linked to the decline in oyster numbers along the west coast of the United States, and to reduced sizes in crabs and other crustaceans in Alaska.

Acidification will also place further pressure on coral reefs already devastated by rising water temperatures. Research shows increased acidity is affecting the ability of polyps to lay down the calcium-carbonate skeletons that support the branches and folds of bony corals, weakening their structure and slowing their growth. Even more disturbingly, research shows reefs exposed to more acidic water will actually begin to dissolve, a process that is already taking place in Florida and Hawaii, and is likely to overtake reefs worldwide by 2050 if current rates of acidification are maintained.

Ocean acidification has a massive impact on some of the ocean's smallest inhabitants, in particular upon the tiny molluscs known as pteropods. These zooplankton, seldom larger than a centimetre in length, are actually sea snails in which the foot has divided to become wing-like appendages that they use to propel themselves through the water. Seen through a microscope pteropods are creatures of extraordinary, otherworldly beauty, their almost transparent wings emerging from translucent shells whose cones and whorls resemble impossibly delicate ice sculptures. The intricate structures of these shells are incredibly thin, ranging from 6 to 100 thousandths of a millimetre in thickness, and as a result, are particularly vulnerable to acidifying waters: placed in water for six weeks with the sorts of acidity levels expected by the end of the century, pteropods' shells simply dissolve. In the Arctic, where melting sea ice is causing rapid changes to ocean chemistry, changes in pteropod shells have already been observed, while Antarctic waters are expected to reach similar levels of acidity within a decade or two.

Krill are also likely to be seriously affected by acidification. Usually no more than a centimetre or two in length, these shrimplike crustaceans gather in vast schools that can spread across hundreds of square kilometres. Although the populations of most krill species are immense, none comes close to that of the Antarctic krill. Even allowing for recent reductions caused by changes in sea ice, Antarctic krill is the most abundant species on Earth, with a population of 300 to 400 trillion and a combined biomass that exceeds that of every human on the planet. Yet even the Antarctic krill's astonishing abundance may not be enough to save it from the effects of acidification: in 2013 a study by Australian Antarctic Division scientists found acidifying waters interfere with the complex life cycle of the krill, and could push them towards a tipping point beyond which their numbers might collapse.

Fish, whales and many bird species rely on krill for survival; crabeater seals alone consume more than 100 million tonnes of krill every year. As the Australian Antarctic Division study noted, in a departure from the carefully anodyne language that characterises most scientific reports, any collapse in krill populations would have "catastrophic consequences" for marine mammals and birds of the Southern Ocean.

It is not really a surprise that we find it difficult to assimilate this sort of information. Our ability to conceptualise fundamental changes to the world we inhabit is extremely limited, as is our capacity to think meaningfully about problems that are years or even decades away. To exist in a moment in which geological time and human time are collapsing into each other is to be brought up against the bounds of our imaginations.

This problem is amplified when it comes to the ocean: although we may know one part of the coastline intimately, the ocean's immensity means that for most of us the rest of the ocean remains essentially unknown, a trackless non-place. Nowhere is this clearer than in the way contemporary travel reduces the ocean to a blue emptiness glimpsed in passing through a window or, just as often, a blue space on a screen.

An awareness of this is one of the things that drives Jennifer Lavers. "People can't care about what they don't know about. You can't inspire people to fight for things they don't even know exist. Ninety-nine point nine per cent of the world's population will never go to Henderson, it's completely off limits. So, for me, it wasn't just about collecting data and crunching numbers; it was about telling a story that helped people feel a connection with these places. I have to show people how beautiful these islands are, how special these species are, how important their ecosystems are, then they can understand the tragedy of what's happening."

Yet there is no question we are on the brink of a moment unimaginable even a generation ago. "We're at a point of complete transformation," says Professor Jessica Meeuwig, director of the Centre for Marine Futures at the University of Western Australia. "A few years ago the French marine biologist Daniel Pauly said that at the rate we're fishing down the food web it won't be long before we'll all be eating jellyfish. A few weeks ago I was in Beijing and I went to the fish markets and where once they would have been full of fish, I was overwhelmed by the amount of jellyfish and other invertebrates that were being sold."

For Meeuwig the situation is doubly frustrating because, when it comes to fish stocks, the real problem is not scientific but political. Like many marine scientists she points to years of studies showing that creating marine reserves covering 30 to 40 per cent of the world's oceans is the only effective way to protect declining fish stocks, but emphasises this strategy is a win-win for fisheries. "The data is really clear. Protecting areas from fishing doesn't just protect fish in the reserves, it increases the economic value of fisheries associated with those reserves." She cites work by Professor Rashid Sumaila of the University of British Columbia, Canada, demonstrating that closing the high seas to fishing would not only increase the number of fish we could catch, as the rising number of fish in the protected areas spilled out into neighbouring waters, but also lay the groundwork for a far more just distribution of the wealth generated by fisheries. "Instead of all the economic benefit flowing to Spanish, Taiwanese and Korean distant-water fishing fleets," Meeuwig says, "countries like Indonesia and nations in west and east Africa would be able to take advantage of their domestic fisheries."

The social-justice dimension of fishery management is seldom discussed, but for Meeuwig it is a vital part of any conversation about fish stocks. "A lot of the pirates in Somalia were former fishermen who could no longer catch fish because foreign fishing fleets had swooped in and trashed the place." Likewise, declining fish stocks contribute to slavery and other forms of labour abuse that persist in the fishing sectors of many countries. Recent reports show Rohingya refugees and Cambodians have been used as slaves on Thai fishing vessels, and Indonesians have been kept in slave-like conditions on South Korean vessels in New Zealand waters.

Meeuwig says that "catches are now so low the only way many distant-water fishing industries can make a buck is through government subsidies or by not paying their labour". She also argues that creating effective marine reserve systems is a key strategy for building resilience to pressures such as pollution and climate change, pointing to studies of the impact of warming waters on kelp forests in Tasmania. "In areas where there was no fishing the kelp didn't collapse because it was more resistant to climate invaders. In the same way research shows that after the flooding in 2011 the areas around Brisbane that were closed to fishing recovered faster, and that areas of the Great Barrier Reef that were closed to fishing have been more resilient to bleaching and crown-of-thorns starfish."

Nonetheless, in March of this year the Turnbull government wound back protections for Australia's marine parks. The move, which more than 1200 scientists had described as "deeply flawed" and "retrograde", opened almost half the area previously classified as protected to commercial fishing. Most contentious was the opening of large areas of the Coral Sea, a region already under assault from climate change, to both recreational and commercial exploitation. Environment Minister Josh Frydenberg hailed the decision as a win for both fisheries and the environment. Meeuwig doesn't mince her words: "The idea we'd actively undermine resilience by allowing fishing in reserves is just incredibly stupid."

Meeuwig is equally direct about where these choices are taking us. "For a long time, scientists have argued that you don't see extinctions in the ocean because broadcast [or mass] spawning makes it difficult to wipe out an entire species. But the only reason it looks different is that we only started industrialising the oceans in the 1960s, whereas we've been industrialising terrestrial environments for thousands of years. So we're just catching up, and that means that we're going to begin seeing extinction rates in the ocean that are unparalleled."

For those working in areas where climate change is the driving force, the situation is even grimmer. "We're at breaking point," says Eelco Rohling. "Sometime in the [next] decade we're going to have to make a choice. Do we keep doing what we're doing or do we go all out and really decrease emissions, not just by some negligible percentage a year, but rapidly and towards zero? Because if we don't do that, we're going to make the planet unliveable."

Jennifer Lavers concurs. "Miners used to take canaries down into the coalmines with them to warn them if the air became poisonous. As long as the birds kept singing they knew it was okay. In the same way, seabirds and other marine species are reliable sentinels of ocean health. And seabirds are declining faster than any other bird group. The birds tell us the tipping point is near."

For coral reefs, that tipping point is already here. Yet those who work on them are wary of allowing despair to colour their work, insisting there is still time to save reefs. As James Kerry argues, "If we say the Great Barrier Reef is written off, then the politicians will write it off."

Despite his prediction that most of the world's coral reefs will be gone within a decade or two, Ove Hoegh-Guldberg also refuses to give up. "The fact we might lose 70 to 90 per cent of corals over the next decade or two shouldn't be our focus. Our focus has to be on the 10 to 30 per cent we can save, and on stabilising global climate as close to 1.5 degrees above pre-industrial temperatures as we can. That's still possible if we make a very rapid shift away from fossil fuels. And that's the double punch we need. We have to get to the lowest levels of CO_2 and other greenhouse gases as fast as possible, while protecting more fortunate regions where the climate may be changing less rapidly. It's incredibly important we protect these more fortunate sites from local impacts such as pollution, overfishing and unsustainable coastal development that is so damaging to reefs. Because they're the places from which regeneration will be possible if we stabilise Earth's atmosphere and climate."

The forces ranged against effective action on climate change and the other pressures transforming the oceans are powerful. But change is possible. In Hoegh-Guldberg's words, "We have to really confront those people who support fossil fuels, and outline the massive environmental and human costs of the path we're on relative to the cost of shifting to low-carbon renewables. The argument we can't switch because it's too expensive is simply baloney. And, quite frankly, reckless. It doesn't cost that much relative to the damage, and we really need to compel our political leaders to stop treating climate change like a second-tier irritation and start treating it as a global emergency."

Achieving that requires people to do more than merely hope. It requires us to take action, not just as individuals but also collectively. As Lavers says, "Hope is an incredibly dangerous thing because it's what we do when we feel we don't have any control anymore. That's why I ask people, I plead with people: don't hope, do. Do something. Do anything. Do whatever you can. At an individual level, at a community level. Don't give up. Don't wave the white flag. Just do something.

The ocean is part of us, part of every living thing. We bear the memory of it in our cells, encoded into our DNA. It affects almost every aspect of life on Earth: influencing the weather, regulating the atmosphere and the temperature, shaping our history and culture. It even suffuses our imaginative lives – its immensity and great cycles of tide and wind and wave speaking to our sense of the infinite, its mystery to our apprehension of time's depth.

Yet while we are accustomed to thinking of the ocean as limitless, it is not. We have pushed many of its inhabitants to the brink of extinction and beyond. We have choked its waters with plastics and other pollutants, leaching poisons into the bodies of fish and other animals as well as ourselves. We have already irreversibly altered its ecology, its biology, even its very chemistry.

Many of the effects of our actions will be felt for millennia. But, despite the scale of the changes we have unleashed, there still remains an ever-narrowing window of opportunity to stave off the worst effects of the disaster that is unfolding around us.

As I write this, the Bureau of Meteorology is reporting that a new El Niño may be building in the Pacific, potentially bringing another round of catastrophic bleaching to the Great Barrier Reef. Perhaps it will be spared this year, but even if it is, the upward trend in water temperatures ensures that in the absence of concerted action to reduce emissions any reprieve will be temporary at best. Whether that happens is up to us. We need to recognise that by failing to act we are making a choice, the effects of which will soon be out of our hands.

JAMES BRADLEY

James Bradley is an author and a critic. His books include *Wrack*, *The Resurrectionist*, *Clade* and *Ghost Species*.

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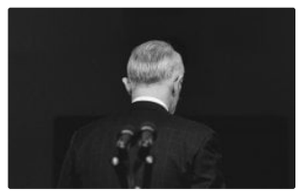

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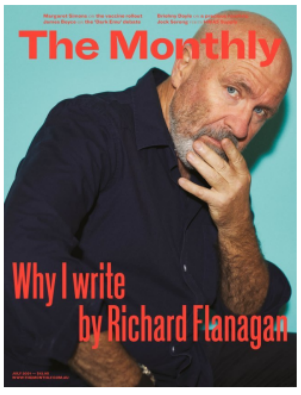

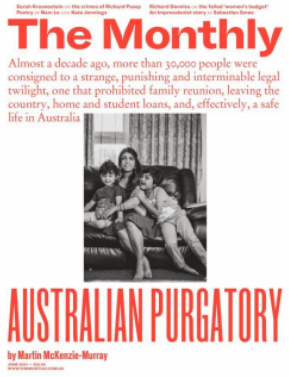

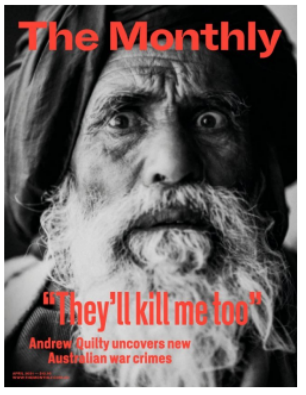

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