

## **Troubled waters**

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### **The sea is suffering, mostly at the hand of man, says John Grimond**

*All of us have in our veins the exact same percentage of salt in our blood that exists in the ocean...And when we go back to the sea...we are going back from whence we came. John Kennedy*

HUMAN beings no longer thrive under the water from which their ancestors emerged, but their relationship with the sea remains close. Over half the world's people live within 100 kilometres (62 miles) of the coast; a tenth are within 10km. On land at least, the sea delights the senses and excites the imagination. The sight and smell of the sea inspire courage and adventure, fear and romance. Though the waves may be rippling or mountainous, the waters angry or calm, the ocean itself is eternal. Its moods pass. Its tides keep to a rhythm. It is unchanging.

Or so it has long seemed. Appearances deceive, though. Large parts of the sea may indeed remain unchanged, but in others, especially in the surface and coastal waters where 90% of marine life is to be found, the impact of man's activities is increasingly plain. This should hardly be a surprise. Man has changed the landscape and the atmosphere. It would be odd if the seas, which he has for centuries used for food, for transport, for dumping rubbish and, more recently, for recreation, had not also been affected.

The evidence abounds. The fish that once seemed an inexhaustible source of food are now almost everywhere in decline: 90% of large predatory fish (the big ones such as tuna, swordfish and sharks) have gone, according to some scientists. In estuaries and coastal waters, 85% of the large whales have disappeared, and nearly 60% of the small ones. Many of the smaller fish are also in decline. Indeed, most familiar sea creatures, from albatrosses to walruses, from seals to oysters, have suffered huge losses.

All this has happened fairly recently. Cod have been caught off Nova Scotia for centuries, but their systematic slaughter began only after 1852; in terms of their biomass (the aggregate mass of the species), they are now 96% depleted. The killing of turtles in the Caribbean (99% down) started in the 1700s. The hunting of sharks in the Gulf of Mexico (45-99%, depending on the variety) got going only in the 1950s.

The habitats of many of these creatures have also been affected by man's activities. Cod live in the bottom layer of the ocean. Trawlers in pursuit of these and other groundfish like pollock and haddock drag steel weights and rollers as well as nets behind their boats, devastating huge areas of the sea floor as they go. In the Gulf of Mexico, trawlers ply back and forth year in year out, hauling vast nets that scarify the seabed and allow no time for plant and animal life to recover. Off New England, off west Africa, in the Sea of

Okhotsk north of Japan, off Sri Lanka, wherever fish can still be found, it is much the same story.



Coral reefs, whose profusion of life and diversity of ecosystems make them the rainforests of the sea, have suffered most of all. Once home to prolific concentrations of big fish, they have attracted human hunters prepared to use any means, even dynamite, to kill their prey. Perhaps only 5% of coral reefs can now be considered pristine, a quarter have been lost and all are vulnerable to global warming.

A hotter atmosphere has several effects on the sea. First, it means higher average temperatures for surface waters. One consequence for coral reefs is that the symbiosis between the corals and algae that constitute a living reef is breaking down. As temperatures rise, the algae leave or are expelled, the corals take on a bleached, white appearance and may then die.

### Hotter water, slimier slime

Warming also has consequences for ice: it melts. Melting sea ice affects ecosystems and currents. It does not affect sea levels, because floating ice is already displacing water of a weight equal to its own. But melting glaciers and ice sheets on land are bringing quantities of fresh water into the sea, whose level has been rising at an average of nearly 2 millimetres a year for over 40 years, and the pace is getting faster. Recent studies suggest that the sea level may well rise by a total of 80 centimetres this century, though the figure could plausibly be as much as 2 metres.

The burning over the past 100 years or so of fossil fuels that took half a billion years to form has suddenly, in geological terms, put an enormous amount of carbon dioxide into the atmosphere. About a third of this CO<sub>2</sub> is taken up by the sea, where it forms carbonic acid. The plants and animals that have evolved over time to thrive in slightly alkaline surface waters—their pH is around 8.3—are now having to adapt to a 30% increase in the acidity of their surroundings. Some will no doubt flourish, but if the trend continues, as it will for at least some decades, clams, mussels, conches and all creatures that grow shells made of calcium carbonate will struggle. So will corals, especially those whose skeletons are composed of aragonite, a particularly unstable form of calcium carbonate.

Man's interference does not stop with CO<sub>2</sub>. Knowingly and deliberately, he throws plenty of rubbish into the sea, everything from sewage to rubber tyres and from plastic packaging to toxic waste. Inadvertently, he also lets flame retardants, bunker oil and heavy metals seep into the mighty ocean, and often invasive species too. Much of the harm done by such pollutants is invisible to the eye: it shows up only in the analysis of dead polar bears or in tuna served in New York sushi bars.

Increasingly, though, swimmers, sailors and even those who monitor the sea with the help of satellites are encountering highly visible algal blooms known as red tides. These have always occurred naturally, but they have increased in frequency, number and size in recent years, notably since man-made nitrogen fertilisers came into widespread use in the 1950s. When rainwater contaminated with these fertilisers and other nutrients reaches the sea, as it does where the Mississippi runs into the Gulf of Mexico, an explosion of toxic algae and bacteria takes place, killing fish, absorbing almost all the oxygen and leaving a microbially dominated ecosystem, often based on a carpet of slime.

Each of these phenomena would be bad enough on its own, but all appear to be linked, usually synergistically. Slaughter one species in the food web and you set off a chain of alterations above or below. Thus the near extinction of sea otters in the northern Pacific led to a proliferation of sea urchins, which then laid waste an entire kelp forest that had hitherto sustained its own ecosystem. If acidification kills tiny sea snails known as pteropods, as it is likely to, the Pacific salmon that feed upon these planktonic creatures may also die. Then other fish may move in, preventing the salmon from coming back, just as other species did when cod were all but fished out in Georges Bank, off New England.

Whereas misfortunes that came singly might not prove fatal, those that come in combination often prove overwhelming. The few coral reefs that remain pristine seem

able to cope with the warming and acidification that none can escape, but most of the reefs that have also suffered overfishing or pollution have succumbed to bleaching or even death. Biodiversity comes with interdependence, and the shocks administered by mankind in recent decades have been so numerous and so severe that the natural balance of marine life is everywhere disturbed.

Are these changes reversible? Most scientists believe that fisheries, for instance, could be restored to health with the right policies, properly enforced. But many of the changes are speeding up, not slowing down. Some, such as the acidification of the seas, will continue for years to come simply because of events already in train or past. And some, such as the melting of the Arctic ice cap, may be close to the point at which an abrupt, and perhaps irreversible, series of happenings is set in motion.

It is clear, in any event, that man must change his ways. Humans could afford to treat the sea as an infinite resource when they were relatively few in number, capable of only rather inefficient exploitation of the vasty deep and without as yet a taste for fossil fuels. A world of 6.7 billion souls, set to become 9 billion by 2050, can no longer do so. The possibility of widespread catastrophe is simply too great.

### **Scramble for the seabed**

*Roll on, thou deep and dark blue Ocean - roll!  
Ten thousand fleets sweep over thee in vain;  
Man marks the Earth with ruin - his control  
Stops with the shore*  
Byron

FOR nearly 30 years, legal control of the sea has actually stopped 200 miles from the shore, but even that is about to change. The 1982 UN Convention on the Law of the Sea allows states to extend their limits beyond 200 miles if they can show that the continental shelf beyond their coastline extends that far. So long as they can produce the necessary scientific data, and so long as the extra margin is at least 100 miles from the point at which the sea reaches a depth of 2.5km, they will be granted rights over the natural resources on and under the seabed up to 350 miles from land. For countries that ratified the convention before May 13th 1999, only four months now remain for the submission of their claims: the deadline is May 13th. A scramble for territory is nearing its climax.

In all, about 15m square kilometres are at stake. That is about half the area involved in the 19th-century scramble for Africa, and some big claims have already been lodged: Canada is seeking 1.7m sq km and Australia 2.5m. Many of the countries that stand to gain most relative to their size, though, are poor and small: Barbados, Mauritius and the Seychelles, for instance. Eight Pacific island nations, among them Fiji, Palau and Tonga, are claiming a total of 1.5m sq km.

The 80 or so countries with realistic hopes of being able to substantiate a claim are not expecting new fishing rights. Their designs are chiefly on minerals. Many people have

for years believed that the seabed was paved with gold, and with some reason. It has long been known that roughly a quarter of the ocean floor is strewn with “manganese nodules”, usually about the size of an apple, which contain not just manganese but also cobalt, copper and nickel. When the law of the sea was being debated in the 1970s, these nodules aroused enormous excitement. It subsided, though, when it became clear that the UN’s proposed arrangements for licensing mining in the deep sea would involve the sharing of technical information with a new International Seabed Authority. America, whose companies were leaders in the field, did not relish parting with its technical secrets and turned against the UN’s planned convention, which it has yet to ratify. Investment in deep-sea mineral extraction came to a halt.

Most Americans dropped their opposition to the convention after its provisions on deep-sea mining were changed in 1994. Even George Bush junior eventually came round to it and American ratification now seems only a matter of time. The United States, however, was not the only obstacle to digging and dredging in the deep. Gathering the nodules was, and is, technically difficult, chiefly because most of them lie in 4km of water, and it was not popular with environmentalists, either, since the necessary dredging stirs up quantities of sediment that kills everything nearby.

The economics of mining has changed, though. Industrial commodity prices, despite recent falls, are much higher than in the 1970s, and technology has advanced. That means it may now become profitable to exploit the manganese crusts and other minerals recently discovered. Several countries certainly hope so. In the past five years China, France, Germany, India, Japan, Russia, South Korea and a consortium of east European countries have all been awarded licences by the International Seabed Authority to explore mining possibilities on the deep-ocean seabed, and a Canadian company, Nautilus Minerals, hopes next year to be the first deep-water mining company to start production. Its plan is to bring up ore containing copper and gold from the bottom of the Bismarck Sea north of Papua New Guinea, using technology developed by the offshore-oil industry.

That industry, with its own purposes in mind, is also keening to move into deeper waters, especially in the Arctic. Rising temperatures and melting ice make Arctic extraction easier, and American government scientists now believe that 90 billion barrels of oil and vast amounts of natural gas still lie beneath the Arctic. Nearly 85% of these deposits, they think, are offshore.

The thought of Arctic oil has quickened more than pulses. Canada is establishing a year-round Arctic presence on land and sea as well as in the air. Denmark is trying to prove that a detached part of the underwater Lomonosov ridge is an extension of Greenland, which is Danish territory. And Russia has staked a claim by sending a submersible to plant a corrosion-resistant titanium flag some 4km below the North Pole.

**Inestimable stones, unvalu’d jewels**

The covetousness goes beyond metals and oil. Two newish discoveries in particular tickle commercial fancies. One is gas hydrates—white, sorbet-like compounds that usually consist of methane molecules trapped in a cage of water. They were first found in permafrost in the 1960s and then, in the 1970s, on the slopes of continental shelves deep beneath the ocean floor.

Many scientists believe these hydrates together contain more energy than all the known deposits of fossil fuels, a possibility that makes them highly attractive to countries such as Japan and India, with little or no oil or gas. The oil companies, though, are cautious. Hydrates occur naturally in pipelines, and are unpopular because they clog the flow of oil. Extracting them would be intensely difficult. And methane, though it burns more cleanly than coal, absorbs a wider range of wavelengths of the Earth's outgoing radiation than CO<sub>2</sub>. It therefore traps more heat, making it an even more pernicious greenhouse gas.

The second discovery is the strange variety of deep-sea life that is increasingly coming to light—quite literally. Some of it is to be found near “black smokers”, vents that occur along ridges in the middle of the oceans where two plates are spreading apart. In such places dissolved hydrogen sulphide comes out of the rock and suddenly cools, causing minerals to condense and create plumes of “smoke”. The first of these vents was discovered in 1977 on the Galapagos ridge by scientists in the Woods Hole Oceanographic Institution's submersible, *Alvin*. A more recent discovery, on the South-West Indian Ocean ridge last year, was made by China's research vessel, *Dayang 1*. Life at the dark depths where these vents occur gets its food and energy from the Earth, not from the sun—and much of it is strange. Here can be found sulphur-eating bacteria, scale worms that thrive in hot water at the tips of the smokers, and shrimps—blind, though they have eyes on the back of their heads—that can mend their DNA even after it has been highly irradiated. And below the crust in these volcanic parts micro-organisms have been discovered that may offer clues to the origins of life.

Much of the interest, though, comes from medical researchers who hope the strange properties of some of these creatures may lead to new anti-carcinogens or tumour-reducing drugs. Some more familiar forms of life, found in much shallower waters, also hold out the promise of new medicines. Sea cucumbers, for instance, are already being harvested and minced up by French and American pharmaceutical companies. Chemicals isolated from soft coral off Western Australia may help fight breast and ovarian cancers.

Old hands cast doubt on theories that huge quantities of minerals lie below the seabed. Big seams are needed if money is to be made. But most of the compounds found so far, say the doubters, come from volcanic deposits. Dissolved minerals—copper, gold, silver and so on—typically rise up with volcanic activity and then become sea-floor deposits; the surface copper in Cyprus, a volcanic island that was once below the waves, is an example. William Ryan, of Columbia University's Lamont-Doherty Earth Observatory outside New York, says there are fewer nodules than people generally believe and most of them are in very deep water. He adds that everything done at sea is becoming more expensive, so the economics of mining may not have improved much. He is equally

sceptical about methane hydrates, arguing that the energy they contain is less than the energy needed to release and secure it.

Such cautions may be wise, but they will not stop the scramble. Too many mysteries of the deep remain unexplained and, anyway, no country turns down a chance to enlarge its sovereignty.

### **The curse of carbon**

*I tell you naught for your comfort,  
Yea, naught for your desire,  
Save that the sky grows darker yet  
And the sea rises higher.*  
G.K. Chesterton

EVEN if they do not live in the Maldives or Bangladesh, most people can appreciate the seriousness of rising sea levels. Much harder to grasp are most of the other consequences of global warming, and especially of the build-up of carbon dioxide in the atmosphere.

About a third of this CO<sub>2</sub> ends up in the sea. Over geological time, virtually all the carbon released into the atmosphere has been taken out of it by living organisms and found its way into sediments, most of them in the sea (some has then gone into petroleum deposits). A vast amount of carbon is swilling about or sitting in the deep sea below 200 metres, where a biological pump pushes it round in such a way that any carbon atom entering the depths from the atmosphere will return to the surface every 500-1,200 years.

The pump is driven by phytoplankton, the tiny plants that constantly convert sunlight and CO<sub>2</sub> into more plants, half of which die or are eaten by zooplankton. In the top 200 metres or so of the sea, some dead or faecal matter is turned back into CO<sub>2</sub> by microbes and may then re-enter the atmosphere. Any that sinks below the sunlit top layers will hang around in the depths for a long time, thanks to the colder temperature and greater density of the deep water. Eventually, currents and upwelling from the depths bring the dead stuff back to the top, where it stimulates more phytoplankton growth. For the duration of its cycle, though, this deep-sea carbon is locked away. In the short term it does not affect the concentration of CO<sub>2</sub> in the atmosphere.

Short-term changes in that concentration are mostly affected by the carbon in the atmosphere itself, the carbon dissolved in the upper layers of the sea and the carbon in plants and animals on land. Until the Industrial Revolution, the exchanges among the three were more or less in equilibrium. But now the concentration of carbon dioxide in the atmosphere is higher than it has been for at least 365,000 years (some say 650,000), even though about half the CO<sub>2</sub> produced in the past 200 years by burning fossil fuels and making cement has gone into the sea. As a result, the sea is 30% more acidic than it would have been without man's new activities.

Even more alarmingly, the processes now set in train cannot easily be stopped, let alone reversed. Though CO<sub>2</sub> in the surface layer is readily exchanged with the atmosphere, the mixing of that water with deeper layers takes several hundred years, meaning the acidification at the top is there for the duration. It is, said Britain's Royal Society in 2005, "essentially irreversible" during the lifetime of anyone alive.

Exactly what this means for life in the sea no one quite knows. One fear is that the increasing acidity will kill off pteropods and similar creatures with calcium-carbonate shells or skeletons. A recent study found the seas acidifying ten times faster than previously believed, with disturbing effects on mussels, oysters and other animals living in coastal regions. But big fish in deeper waters might also be affected if entire species were lost at the bottom of the food web. Another worry is that the eggs and larvae of some fish may be unable to survive in more acidic water, and that creatures like squid which need a lot of oxygen will also die out. Any shortening of the food chain is likely to destabilise entire ecosystems, possibly leading to new ones in which just one or two species, such as jellyfish, predominate.

A different set of concerns surrounds coral. Coral reefs, which have evolved over 400m years, are the biggest living structures on Earth and the richest in terms of marine biodiversity. A quarter of all sea species spend at least a part of their life in a reef—and many reefs are in cold or temperate waters. Their bounty already puts them at risk from fishermen. The Darwin Mounds to the north-west of Scotland, for instance, which support extensive colonies of cold-water coral, were smashed up soon after their discovery in 1998 by trawlermen eager to get at the fish. Similar damage has been done to reefs off Norway.

Yet coral is also at risk from acidification, and more so in colder waters even than in tropical ones, since colder seas tend to be more acidic. If the seas continue to become less alkaline at the current rate, the time will soon come when reefs will start to lose coral faster through erosion than they gain it through calcification. How soon? Some scientists think it could be in 60 or 70 years. Many fear that half the world's coral will be gone by 2030.

The other aspect of man-made carbon-dioxide production that affects the sea is global warming itself. Though the oceans heat up more slowly than the land, higher temperatures are already causing them to expand. Indeed, expansion is now raising sea levels by at least 10-20cm per century (they rose about 30cm in the 20th century). The melting of glaciers, ice caps and polar ice sheets on land, however, has the potential to account for much more. The Arctic has lost over 40% of its year-round ice since 1985, 14% in 2004-05 alone. This will not do much directly to raise sea levels, because most Arctic ice is floating, but it suggests that the melting is speeding up, and that is confirmed by the flow of the Jakobshavn glacier in Greenland, which doubled in speed between 1997 and 2003.

### **From Greenland's icy mountains**



Most scientists think East Antarctica is stable, because it is high and dry, meaning a temperature rise of a few degrees will cause no melting. But if even half of the West Antarctic and Greenland ice sheets were to melt, sea levels would rise by six or seven metres, flooding many of the world's big cities, and the outlook is discouraging. Over the past 50 years the fastest rise in temperatures on Earth has been on the Antarctic Peninsula, in the west of the continent; this has been matched only in Alaska. And last year the Wilkins shelf, a huge plate of floating ice attached to the peninsula, started to break up, losing some 2,000 sq km in six months. The eighth ice-shelf collapse on the peninsula in 30 years, it is further evidence of an acceleration in warming. West Antarctica as a whole lost ice about 75% faster in 2006 than in 1996.



The melting of an ice shelf, which is merely a floating projection into the sea, would not affect sea levels. It would take the melting of an ice sheet to do that. Yet that is just what is happening in Greenland, whose relatively warm and wet sheet is on course to melt completely, bringing the prospect of a sea-level rise of perhaps seven metres. The big question is when, and that is unanswered. The Intergovernmental Panel on Climate Change in 2007 forecast a rise of 18-59cm this century. Many think this much too conservative.

When sea ice melts, the newly exposed dark water absorbs radiation rather than reflecting it, as snow or ice would. That raises the temperature of the sea, making the ice melt even faster. Something similar happens when terrestrial ice melts. Either it exposes land, which then warms up; or it forms ponds (or lakes or streams) of meltwater on the surface of the ice, which absorb energy and melt more ice. Both mean a loss of heat-reflecting ice and a net addition to global warming.

One related concern seems to have abated, though. For some time scientists were puzzled by the speed with which meltwater could disappear through the ice as it drained down natural pipes known as moulins. A meltwater lake on the Greenland ice sheet that contained 44 billion litres and covered 5.7 sq km gurgled away within 24 hours in 2006. Most of it went in 90 minutes, at a rate that at its maximum was faster than the average flow of the Niagara Falls. The fear was that when this quantity of water hit the bottom, it would detach the ice from the bed on which it rested and lubricate its passage to the sea.

Not so, it seems, to judge by a study published last year by Sarah Das, of Woods Hole. The meltwater did indeed cut through nearly 1km of ice, as some had hypothesised and others had doubted, forcing its way down thanks to its greater weight and density. But it did not destabilise the ice sheet or provide a new reason to worry about rising sea levels.

Even if it meant nothing for sea levels, though, a melting Arctic still means a lot for the ecology of the region. Polar bears, for example, are becoming endangered, as the disappearance of ice obliges them to swim farther and farther to catch seals, their main prey. In contrast, some humans are delighted by the new warmth. Greenlanders can now grow potatoes, miners are eyeing newly accessible mineral reserves and trawlermen can more easily pursue fish into northern waters.

Most excited of all, though, are oil-drillers and shipping companies. Shell Oil, frustrated last year by lawsuits filed by environmentalists and Alaskan natives, is eager to start exploiting its leases in the Beaufort Sea. Russian companies such as Gazprom are already developing fields in the Barents Sea. And Russia, like America, thinks the Arctic holds lots more oil and gas. It believes that the territory it considers to be rightfully its own—it lodged a claim for 1.2m sq km of seabed in 2001—holds 586 billion barrels of oil, more than twice Saudi Arabia's proven reserves. In this it may be wrong, but there is no doubt that fossil fuel, the very agent that is destroying the Arctic, will become far more available as a result of the destruction it wreaks. In all, the Arctic may hold 20-30% of the world's undiscovered oil reserves.

Soon shipping will join the polluters of the north. A new seaway through an unfrozen Arctic Ocean would cut the journey from Rotterdam to Yokohama via the Suez canal by 4,700 miles, a saving of 42%. From Rotterdam to Seattle via the Panama canal, the saving would be 2,000 miles, over 20%. Ships too big to go through the Panama canal would save even more.

Would the financial savings be commensurate? If it cost no more to sail through the Arctic than anywhere else, yes: the savings per voyage would be huge. But even if the ice

melts as fast as shippers hope (and scientists fear), navigation is likely to demand strengthened hulls, higher insurance and extra training for crews, all adding to the costs.

Everything depends on the speed at which the ice disappears. Computer models have been predicting that the Arctic will not be ice-free, even for a short time in late summer, until 2040, and at present only icebreakers and the occasional lone yachtsman are getting through. But some people believe change is coming so fast that the northern seas will open up much earlier than expected. They may be right.

If so, it will be seen as a harbinger of another horror: the prospect of a shutdown of the North Atlantic conveyor. This is the current of water that takes enormous amounts of heat—about as much as would be generated by a million nuclear power plants—from the tropics and carries it to eastern North America and western Europe. The fear is that melting ice, along with increased snow and rain, could reduce the density and salinity of the top layers of the sea, making them more buoyant. At present, the conveyor depends on surface water sinking and travelling towards the equator, there to rise again and bring warmth back to the north (see map in the introduction). If this current stopped, the average temperature in Europe might fall by five to ten degrees Celsius.

### **More abused than used**

*Sad were my thoughts that anchor'd silently  
Of the dead waters of that passionless sea  
Unstirr'd by any touch of living breath:  
Silence hung over it, and drowsy Death,  
Like a gorged seabird, slept with folded wings  
On crowded carcasses—sad passive things*  
Thomas Hood

OF ALL the blights afflicting the sea, carbon dioxide is just one. Man has used the oceans as a dustbin for far too long.

The bin would be even fuller and fouler had the London dumping convention not been signed in 1972, but the sea is still hideously polluted. Over 60m litres of oil run off America's streets and via rivers and drains find their way into the oceans each year. Through sewage and medical waste, antibiotics and hormones enter the systems of seabirds and marine mammals. Mercury and other metals turn up in tuna, orange roughy, seals, polar bears and other long-lived animals.

So does radioactive effluent, whether from Sellafield, a nuclear reprocessing plant on the west coast of England, or the scrapyards of Russia: between 1958 and 1992, the Arctic Ocean was used by the Soviet Union, or its Russian successor, as the resting-place for 18 unwanted nuclear reactors, several still containing their nuclear fuel. All over the world, oil spills regularly contaminate coasts.

More alarming still is the plague of plastic. The UN Environment Programme reckoned in 2006 that every square kilometre of sea held nearly 18,000 pieces of floating plastic. Much of it was, and is, in the central Pacific, where scientists believe as much as 100m tonnes of plastic jetsam are suspended in two separate gyres of garbage over an area twice the size of the United States.

About 90% of the plastic in the sea has been carried there by wind or water from land. It takes decades to decompose or sink. Turtles, seals and birds inadvertently eat the stuff, and not just in the Pacific. A Dutch study of 560 fulmars picked up dead in countries around the North Sea found 19 out of 20 had plastic in their stomachs—an average of 44 pieces in each. Moreover, when plastic breaks up it attracts toxins, which become concentrated in barnacles and other tiny organisms and thus enter the marine food chain.

Some action is being taken. Volunteers work to catch at least some of the plastic pellets—hundreds of millions each week—that are washed out to sea by the Los Angeles river. Oil spills should become rarer after next year, when all single-hulled ships will be banned.

Efforts are also being made to prevent the spread of invasive species through the taking on and discharging of ships' ballast water. The worry is that creatures like the Chinese mitten crabs that have been introduced to San Francisco Bay (along with 175 other alien species), for instance, may spread to other places, overwhelming the native varieties. A "global ballast partnership" hopes to reduce this risk. Similarly, a UN convention may soon ban the use of tributyltin, a highly toxic chemical once added to the paint used on almost all ships' hulls, in order to kill algae and barnacles.

Shipping itself is a huge cause of pollution. The International Maritime Organisation said last year that sea transport accounted for only 2.7% of total emissions in 2007. But leaks last year from an unpublished report by the Intergovernmental Panel on Climate Change put the figure at nearly 4.5%, about twice as much as the share of aviation. And, though shipping is now in decline, by 2020 emissions are expected to rise by 30%. Since ships burn bunker oil, the dirtiest of fuels, that means not just more CO<sub>2</sub> but also more "particulate matter", which, according to a controversial paper published in 2007, is already responsible each year for about 60,000 deaths from chest and lung diseases, including cancer. Most of these occur near coastlines in Europe, East and South Asia.

Various measures could reduce this pollution. Some ships are already going slower, to save fuel; some are also burning cleaner, low-sulphur oil; some journeys are becoming unnecessary, as rising costs make it unprofitable to send food, for instance, from America to be processed in Asia and then carried back to where it came from. And shipping could, and should, be included in all carbon-trading schemes, notably the EU's.

In principle, it should also be possible with concerted action to arrest, if not reverse, another growing problem, the rise of slime. This is a term coined by Jeremy Jackson of the Scripps Institution of Oceanography at the University of California in San Diego, here used as shorthand for the increasingly frequent appearance of dead zones, red tides and

jellyfish. All these seem to have occurred naturally for centuries, and still do. Red tides, for example, regularly form off the Cape coast of South Africa, fed by nutrients brought up from the deep, and off Kerguelen island in the Southern Ocean. Nowadays, though, most are associated with a combination of phenomena including overfishing, warmer waters and, often, the washing into the sea of farm fertilisers and sewage.

In shallow coastal waters, most of the fish tend nowadays to have been caught. As the larger species disappear, so the smaller ones thrive. These smaller organisms are also stimulated by nitrogen and phosphorous nutrients running off the land. The upshot is an explosion of growth among phytoplankton and other algae, some of which die, sink to the bottom and decompose, combining with dissolved oxygen as they rot. Warmer conditions, and sometimes the loss of mangroves and marshes, which once acted as filters, encourage the growth of bacteria in these oxygen-depleted waters.

The result may be a sludge-like soup, apparently lifeless—hence the name dead zones—but in truth teeming with simple, and often toxic, organisms. These may be primitive bacteria whose close relations are known to have thrived billions of years ago. Or they may be algae which colour the sea green, like the carpet of weed in Qingdao that nearly brought the sailing to a halt in last year's Olympic games. Sometimes they colour it red, but this is less the wine-dark sea of Homeric fame than the red-brown waters of Florida's Gulf coast—or Chesapeake Bay, or the Adriatic, or Hiroshima Bay, or the inlets of New South Wales. In such places red tides tend to form, some producing toxins that get into the food chain through shellfish and rise up to kill bigger fish (if there are any left), birds and even seals and manatees. Occasionally, the poisons waft ashore to fill clinics with coughing patients.

In other places, such as Australia, Spain and Namibia, the plague brings a different form of simple, invertebrate life, the jellyfish. As other fish disappear, these plankton-eating organisms move in, to the despair of swimmers and the consternation of fishermen. Some trawlermen, however, have adapted, abandoning more conventional catches in favour of jellies. Nearly 500,000 tonnes of these creatures were caught in 2006, most of them in Asia and destined to be eaten in soup or salads by Chinese or Japanese.

Red tides and similar blights do not necessarily last long, nor do they cover much of the surface of the sea. But they are increasing in both size and number: dead zones have now been reported in more than 400 areas. And increasingly they affect not only estuaries and inlets, but also continental seas such as the Baltic, the Kattegat, the Black and East China Seas and the Gulf of Mexico. All of these, point out Robert Diaz and Rutger Rosenberg, authors of a report last August in *Science*, are traditional fishing grounds.

The spread is exponential, they say. The direction is just as worrying. The winners in these newly polluted, over-exploited, oxygen-starved seas are simple, primitive forms of life, whereas the losers are the ones that have taken aeons to develop. Algae, bacteria and jellyfish thrive while fish, coral and sea lions die. It is, wrote Kenneth Weiss of the *Los Angeles Times* in 2006, as if “evolution is running in reverse”. And though a few ideas have been put forward to reduce fertiliser runoffs—a cap-and-trade system for nitrogen

polluters, similar to those for European carbon polluters, for instance—it is hard to see a solution. Not enough is known about the causes of the problems, and too many of the agents are far removed from the scene of the event.

### **Realms of ocean, fields of air**

Have all marine resources been abused or exploited to the point where the sea can do nothing more for man? No. It still has much to offer, especially in helping to solve one of the very problems from which it suffers itself, CO<sub>2</sub>-induced global warming.

The most beguiling idea is to speed up the rate at which carbon is taken out of the atmosphere and into the sea: increase the concentration of CO<sub>2</sub> in the oceans by 0.5% and the concentration in the atmosphere returns to pre-industrial levels. The trouble is the sea then becomes an acid bath. Even so, some people think it can still help.

One popular idea is to use iron to fertilise the sea, causing the same explosions of phytoplankton that often precede dead zones and red tides. If this were to happen in the deep sea, the carbon absorbed by the plankton through photosynthesis would descend to Davy Jones's locker for several hundred years. It was this thought that caused John Martin, once head of the Moss Landing Marine Laboratories in California, to declare, "Give me half a tanker of iron, and I'll give you an ice age." Laboratory experiments suggested that every tonne of iron sprinkled on the sea would remove 30,000-110,000 tonnes of CO<sub>2</sub> from the air.

Several companies are now trying to put this into practice and thus make money by selling carbon credits. One trouble, though, is that very little of the carbon drawn into the sea by plankton sinks far enough down before it is eaten by other plankton and recycled into the atmosphere. Another drawback is that the side-effects are largely unknown and potentially horrible if, for example, a "weed" species were to take advantage of a changed ecosystem. At best this scheme offers a small and temporary benefit.

Two other ideas are more promising. One is to capture CO<sub>2</sub> and store it under the seabed. David Goldberg and Taro Takahashi of Lamont-Doherty believe that nearly 150 years' worth of the United States' CO<sub>2</sub> production could be injected into 78,000 sq km of subsea rock off western North America. The basalt and the CO<sub>2</sub> would react with each other, reducing the scope for leaks, which would be further diminished by the blanket of sediment that covers the ocean floor in that area.

Though it is harder to pump CO<sub>2</sub> into saline aquifers or disused oil wells in the sea than on land, the idea is still attractive, and certainly less risky than another proposal, which is simply to dump the captured CO<sub>2</sub> on the floor of the deep ocean, where pressure and temperature would keep it liquid and well away from the atmosphere. Currents, however, might stir it more than expected, and it would react with the water above it. This might lead to the formation of hydrates, which could be unstable if disturbed, and it might also lead to a lake of CO<sub>2</sub> on the ocean floor which would be acidic at the margins.

An altogether different, and better, idea is to use the sea to generate green, CO<sub>2</sub>-free energy. The sea offers three ways of doing this. The winds—whose energy derives from the sun, via the convection of air currents—are increasingly harnessed by windmills both on- and offshore. The advantage of having them at sea is that they can occupy unused open space and ruin fewer views than on land. But wind power is uncertain, sometimes providing too much electricity and sometimes too little.

That is true of wave power, too, which also gets its energy from the sun, in this instance via the winds. The first commercial wave-power farm started producing electricity last year off Aguçadoura in northern Portugal, using one of several available designs, this one developed in Scotland. Its first aim is to provide enough power for 1,500 homes, and ultimately nine or ten times as many. Rival technologies are being developed in Canada, the United States and elsewhere, and some are operating, for example, off Hawaii and the west of Scotland.

A better bet, at least in terms of continuity of production, is tidal power, whose energy comes from the gravitational pull of the sun and moon. A few tidal projects, such as the 42-year-old barrage at Rance in France, operate like traditional hydro schemes, in which tidal water simply rushes through turbines. Most others use the principle of an underwater windmill whose rotors are turned by the tide. The leading test centre is in Orkney, off north-east Scotland, where the winds blow and the tides race as in few other places.

One trouble with tidal power is the difficulty of servicing underwater installations. Another is ensuring that they do not get carried away in storms: Orkney's climate may yet prove too wild. And, like all marine energy, tidal power may be easiest to produce in places where it is least needed—far away from centres of population, where connections to the national grid would be expensive. New York, though, could be an exception: a tidal scheme is now being tested in the East River. South Korea's Sihwa Lake tidal plant, planned to open this year, will also serve a neighbouring city, Ansan, with 690,000 people.

### **Plenty more fish in the sea?**

*Gaze upon the rolling deep  
(Fish is plentiful and cheap)  
As the sea my love is deep!  
Said the Yonghy-Bonghy-Bó.*

Edward Lear

THE sea is still deep, and fish may still be relatively cheap, but it costs much more than it used to. And it is far from plentiful.

This has become a commonplace. People have long been told that the North Sea is fished out and that the waters of the North Atlantic closest to Europe now produce only a

fraction of the bounty of the 1940s. Books, articles and reports regularly record the decline. In 2004, for instance, a British royal commission described in bleak detail the collapse of north-east Atlantic cod, of North Sea hake and plaice, and of other species discarded as “bycatch” and thrown back dead into the sea in huge numbers.

Americans have heard similar stories. An authoritative report from the Pew Oceans Commission told them in 2003 that, of the American fish populations that had been assessed, 30% were being overfished, many of them unsustainably. Books like “Cod”, by Mark Kurlansky, have eloquently described how the fishing grounds that stretch from the shallow waters off Newfoundland south to Georges Bank, once considered the richest in the world, have come to be commercially moribund. Governments, though slow to respond, have not been wholly blind to the changes. Canada’s closed the Grand Banks in 1992. Fishermen themselves have seen the evidence, and not just there. In the 1970s, for instance, West Coast trawlers were landing 11,000 tonnes of bocaccio a year. In 2001, just before the fishery was closed, the catch was 214 tonnes. It will take at least 90 years, say scientists, for the stocks to recover.

And overfishing is not just a problem of northern fisheries. A paper published in *Nature* in 2003 carried 13 charts showing the catch per 100 hooks in different fisheries from the temperate Pacific to South Georgia in the southern Atlantic, and from the Gulf of Thailand to the St Pierre Bank off Labrador. Each chart displayed a similar precipitous descent in the catch from the start of industrial fishing, some time before 1960, to a virtual plateau between 1980 and 2000. “Our analysis”, said the authors, Ransom Myers and Boris Worm of Dalhousie University in Canada, “suggests that the global ocean has lost more than 90% of large predatory fishes.” These are the ones, cod, groupers, salmon, tuna and so on, that everyone likes to eat.

An even gloomier assessment came in an article by 14 academics in *Science* in 2006. The accelerating erosion of biodiversity, often associated with overfishing, presaged a “global collapse” to the point, in 2048, where all species currently fished would be gone, they said.

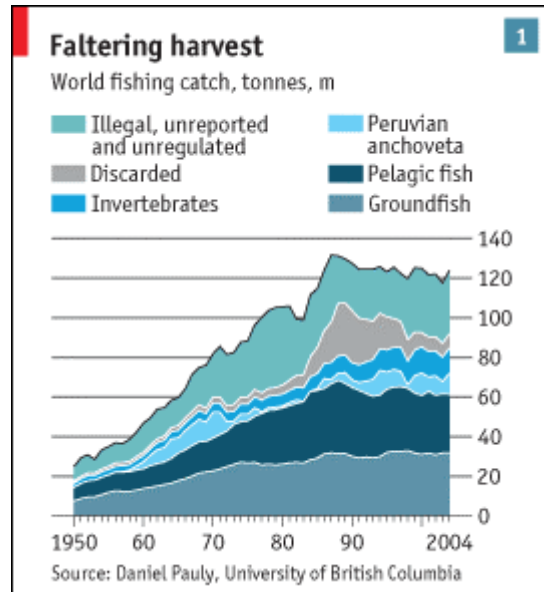
### **The mackerel-crowded seas?**

Even many scientists who are alarmed by the evidence of overfishing find such conclusions controversial. Most non-scientists are unmoved. For a start, fish appears to be in plentiful supply. Even cod is available; over 7m tonnes of cod-family (*Gadidae*) fish are caught each year. Sushi bars have spread across the world. To cater for the aversion to red meat, and a new-found need for omega-3 fatty acids, fish dishes are on every menu, even in steak houses. Supermarkets and restaurants boast of “sustainable” supplies, and sandwiches are reassuringly labelled “dolphin-friendly”, however threatened the tuna within them may be. Best of all, for the ethical consumer, fish are now farmed. Salmon has become so plentiful that people weary of its delicate taste.



Moreover, fishermen themselves seem sceptical of any long-term scarcity. They clamour for bigger quotas and fewer restrictions (except on foreign competitors), and complain that the scientists are either ignorant or one step behind the new reality. Those with long memories can cite previous collapses that have been followed by recoveries. And, in truth, not all collapses are due solely to overfishing: the sudden crash of California's sardine industry 60 years ago is now thought to have been partly caused by a natural change in the sea temperature.

Plenty of figures seem to support the optimists. Despite the exploitation round its coasts, Britain, for instance, still landed 750,000 tonnes of Atlantic fish in 2006, two-thirds of what it caught in 1951; even cod is still being hauled from the north-east Atlantic, mostly by Norwegians and Russians. Some British fishing communities—Fraserburgh, for example—are in a sorry state, but others still prosper: the value of wet fish landed in Shetland, for example, rose from £21m in 1996 to £54m (\$33m-99m) in 2006. Earnings from fishing in Alaska, in whose waters about half of America's catch is taken, rose from less than \$800m in 2002 to nearly \$1.5 billion in 2007. And for the world as a whole, the catch in 2006 was over 93m tonnes, according to the UN's Food and Agriculture Organisation, compared with just 19m in 1950 (see chart). Its value was almost \$90 billion.



The main reason was that fishermen were still able to exploit their relatively new ability to find and catch their prey. Most underwater creatures had little to fear from man until 1873, when the first steam-powered whaling ships, armed with explosive harpoons, were launched. Whales were then ruthlessly pursued, several species almost to extinction, until hunting was banned in the 1980s.

The steam-powered trawler came next, in 1881. When fitted with an otter trawl, invented in 1892, it enabled fishermen to haul in six times the catch of a sailing ship. Soon came filleting machines, echo-sounders and spotter planes. Then Clarence Birdseye, an American fur-trapper turned inventor, developed a system for freezing fish. This gave the world the fish finger and launched the factory ship that sailed far from home and processed the catch from huge trawlers on the high seas.

Next came the cold war, whose main casualty may have been fish. The technology designed by America's Office of Naval Research developed to find the Soviet Union's submarines and hide NATO's was soon put to use in the pursuit of haddock, herring and

every other kind of underwater prey. After that came satellites and with them global positioning systems and thermal images, enabling fishermen to find the places where warm and cold waters collide, which is where plankton flourish and fish gather. Now an array of technology—acoustic fish-finders, broad-swath mapping of the seabed, computerised track plotters and so on—make it possible to find most fish bigger than a man's forearm.

### **There goes that Leviathan**

The biggest ones have been the first to go. As a result, in over-exploited waters the fish tend to be smaller and younger. Among those caught in the Pacific, the average length of an English sole fell from about 34cm in the 1960s to 30cm in 2002, a Pacific barracuda from nearly 80cm in the 1950s to 65cm in 1970, a bocaccio from over 50cm in the 1970s to nearer 45cm in the 1990s. Whereas record-sized cod 2 metres long and up to 96kg (211lb) in weight were recorded in Massachusetts in the 19th century, and an average of 4.5kg per fish was common in living memory, a big cod is now a rarity in the north-west Atlantic. And when the big fish are gone, smaller varieties become the new catch. "Fishing down" the food web, as the practice is known, resulted in the average length of fish caught off the west coast of Newfoundland falling by a metre between 1957 and 2000, according to an article by Daniel Pauly and Reg Watson, of the University of British Columbia's Fisheries Centre, in *Scientific American* in July 2003.

When stocks of familiar fish are exhausted in familiar fishing grounds, man turns towards new fish in new places. Distant-water ships from such countries as Taiwan, South Korea and Russia have been ploughing far-flung oceans ever since the art of freezing fish became simple. "Klondikers", huge factory ships from eastern Europe, started to turn up in foreign waters in the 1990s. Spanish boats, following the traditions of the medieval Basques, fish all over the world. Ships from Bulgaria, China, Japan, Mexico, Poland and Romania can all be found far from home.

There they set about repeating what they have done in their own waters. Having caught almost all the northern bluefin tuna in the Mediterranean and many of the fish off other coasts, the countries of the European Union, for example, have negotiated rights to fish in coastal waters off west Africa. Now stocks of octopus, lobsters, tuna and other fish in this part of the Atlantic are dangerously low, contributing to the impoverishment of local fishermen. As a result, many are said to be driven to such desperate measures as eating bushmeat from endangered animals and setting sail in open boats in the hope of illegally settling in Europe.

Rich-country consumers of Senegalese shrimps or Omani lobsters are no doubt delighted with their *entrées*. Others may need a little encouragement to buy fish hitherto unknown to them. Many species are therefore renamed for the retail trade: bocaccio, a kind of rockfish, becomes Pacific red snapper, Patagonian toothfish becomes Chilean, or Australian, sea bass, and dogfish becomes rock salmon.

## **Creeping things innumerable**

In British fish-and-chip shops pollock and coley are increasingly used in place of cod, and in American fast-food outlets Alaska pollock has become the staple. But in 2008 stocks of Alaskan pollock shrank by half, leaving what is believed to be the world's largest food fishery poised on the brink of collapse. This could be a natural fluctuation. So could the disappearance of chinook salmon from the waters off California and Oregon last year; the population during the spawning season was 88% below its all-time high in 2003.

Most fish-watchers, however, are uneasy. They see too many signs of overfishing, and too few of recovery. One of the most recent objects of concern is a small, shrimp-like creature called krill, which is now being fished in a big way. Krill spend their days in the depths of the sea, rising at night in what they believe to be the safety of darkness to snack on phytoplankton. In fact, they are likely to be hauled out by fishermen, especially if they are in the waters of Antarctica. Krill do not end up on plates in restaurants, except perhaps in Japan or Russia, but they are increasingly in demand for their fatty acids, for their enzymes (used in medicine), for feeding to farmed fish, especially to give the flesh of salmon a pink appearance, and for use as fish meal. And now a technique has been developed that enables trawlermen to process them at sea before their enzymes decompose. This means ships can stay longer away from port and multiply the size of their annual catch many times.

## **What are the wild waves saying?**

No one thinks krill are yet endangered, but no one fully understands them. It is known, however, that many whales and seals and penguins live on them. And it is known that the plankton they eat cling to the underside of packed ice, ice that may start melting as temperatures rise. The fear is that devastating the krill population will set in train a series of changes that will affect other creatures.

This is, after all, what is happening in other places, though usually the changes start at the apex of the food web. Typically, this is a fish-eat-fish affair, with vegetarians like krill taking their place at the bottom (phytoplankton are plants, whereas zooplankton are animals). Thus the relentless hunting of big sharks off the United States' Atlantic coast has rendered them unable to "perform their ecosystem role as top predators", in the words of Julia Baum of Dalhousie University. The upshot is a huge increase in the numbers of their prey, notably ray, skate and smaller sharks. Cownose ray, which may grow to be over a metre in width, are increasing by about 8% a year. With some 40m of them now looking for food off the East Coast, the shellfish they eat, such as scallops, oysters and clams, have been devastated.

One lesson here is that no species should be fished to the point where the ecosystem is unbalanced. That conclusion hardly requires the fish-fed brain of Jeeves. Another is that,

to maintain a balance, big “apex” fish may be as important as small. Many fish take years before they are mature enough to spawn: cod, three or four, sturgeon 20, orange roughy 32. And they may be long-lived: cod can survive to 30, if they are lucky, and sturgeon to 100. Kill the fish at the top and you may get an explosion of smaller ones below, gobbling up much more food than would be eaten by a few big fish of the same total weight. And big fish provide more and better-quality fry. Take the big and leave the young, a common principle of fisheries managers eager to rebuild stocks, may therefore be a mistake. If so, it is not their only one.

### **Come, friends, and plough the sea**

*“Will you walk a little faster?” said a  
whiting to a snail,  
“There's a porpoise close behind us, and  
he's treading on my tail.”*

Lewis Carroll

FOR most of man's existence he has been a hunter-gatherer. These days, however, it is as a farmer that he harvests almost all his food from the land. Now he has started farming the sea, too. The world produced 48 billion tonnes of farmed fish in 2005, worth \$71 billion. That was 34% of the total, a proportion that is likely to rise to half by 2010. A huge variety of fish, including cod, crayfish, bream, halibut, mussels, salmon, sea bass and sturgeon, are all farmed, providing jobs and food for people all over the world.

Unfortunately, fish farming is still in its infancy and in some places may do more harm than good. In Indonesia, Thailand, Vietnam and other parts of Asia, huge swathes of coastline have been denuded of trees to make way for ponds and pens. Many fish farms create pollution, too. Even if the water in which the fish are reared starts out fresh, the build-up of faeces and uneaten food soon makes it foul. The mix is made even nastier by the pesticides and antibiotics needed to keep the crop alive. And to cap it all, aquaculture produces CO<sub>2</sub> and gobbles up energy.

China, which produces about 70% of the world's farmed fish, has been a notable offender in creating such pollution. Many of its fish have been found to contain heavy metals and toxic chemicals. But China is not alone. When salmon farming first started in Europe, the fish often became infested with lice, which then spread to wild fish. The drugs to treat them contributed to the pollution of the waters, already contaminated by the growth hormones and antibiotics added to the food.

Similar problems still arise elsewhere. Millions of fish were killed last year when a virus called infectious salmon anaemia swept through Chile's salmon farms. Many blamed the outbreak on intensive farming. Farmed fish are also prone to parasites, one of which, *Gyrodactylus salaris*, has infected about 10% of Norway's rivers, wiping out the wild salmon. Farmed fish also do damage when they escape, as many do. Sometimes the

escaped fish interbreed with wild fish to the detriment of the local stock. Sometimes they eat the young of their rivals. Always they compete for food.

The solutions to these problems are often known, if not applied. They usually involve fewer farms, colourings and pesticides, and cleaner water. But some difficulties are more complicated.

### **Cod's head for salmon's tail**

Some fish, such as groupers and eels, do not breed in captivity. They must be reared from fish caught in the wild, whose stocks are thereby reduced. And most of the fish that people like to eat are predators, which means they must themselves be fed fish. This is not an efficient business. It takes at least three kilos of fish meal to add one kilo to the weight of a farmed salmon. Most of this meal is made of ground-up anchovies, menhaden or sardines. Such forage fish already account for nearly a fifth of the world's total annual catch; another fifth goes to feed pigs and poultry. Increasingly, as these small and middle-sized fish run out, smaller and hitherto commercially worthless ones are scooped up in fine-meshed nets. With them are quantities of tiddlers that, were they to survive, would grow into bigger, commercially valuable fish.

They might be ecologically valuable too. The striking drop in numbers round British coasts of such seabirds as arctic terns, kittiwakes, guillemots and puffins is probably a result of the disappearance of sand eels. These have either fled north to stay cool or been fished to the last elver before being turned into salmon feed.

Perhaps the most grotesque form of fish farming is the ranching of bluefin tuna, a delicacy that may sell for as much as \$860 a kilo. Bluefins are sensitive creatures that hate being cooped up so much that, if confined, they tend to throw themselves against their cages and break their necks. Australian "ranchers" have now adopted a technique that involves catching young bluefins, enveloping them in a huge net and dragging it slowly round the south seas for months while feeding them pilchards imported from west Africa.

If fish are to be farmed in ever greater numbers, most had better be plant-eaters. Even better, from an environmental point of view, are molluscs such as mussels, clams and oysters. These need no feeding, thriving on plankton alone. They may even clean the water they live in. The main damage associated with farming shellfish is caused by harvesting them with dredges, which ruin the seabed. Fortunately, they can be gathered by divers.

### **Grabbing it all**

*With friends like these, who needs anemones?*

## “Finding Nemo”

THE politicians who make fisheries policy may sometimes be excused if they are confused. Knowledge is incomplete, and natural systems are not necessarily stable. Paradoxes and surprises abound.

An abundance of fish, for example, is not always a sign of health in a fishery: the profusion of one species may simply be a temporary consequence of the depletion of its predators. On the other hand, a profusion of stressed, smaller fish may actually be a sign of a balanced ecosystem.

This is suggested by observation of pristine coral reefs in the middle of the Pacific. Researchers from Scripps who have looked at those around Palmyra, an atoll some 1,600km south of Hawaii whose marine environment is largely untouched by man, have been surprised by the large numbers of such predator fish as sharks and groupers; in fact the predators seem to outnumber the prey. For Stuart Sandin, one of the researchers, the profusion was a puzzle. What are these big fish feeding on?

The answer is smaller fish. But those round Palmyra are not merely smaller, they are smaller than they would be if they were not hunted. In other words, in a state of nature, for that is pretty much what Palmyra is, the apex fishes' prey seems to be in a permanently stressed condition. Yet the prey can maintain their numbers by growing fast, reproducing fast and eating not just the next victim below them in the food web but also algae. And these algae would soon take over and destroy the reef if they were not being eaten by fish. So stressed middle-sized fish make for both happy coral and happy predators—in short, a healthy and highly productive reef. It will remain so over time, even recovering from shocks like the bleaching Palmyra experienced in 1998, if it is not unduly disturbed.

One lesson therefore is to avoid unbalancing the marine environment. The other is to take a long-term view. Neither of these comes readily to politicians. Unless the briny is lapping at the door, which generally takes a hurricane, politicians give little thought to the sea. Their concerns start and end with fishermen, who in most rich countries are few in number but well organised as lobbyists. And though most fishermen have a strong interest in the long-term productivity of the sea, they also have a short-term interest in maximising their incomes and paying for the very expensive ships and equipment with which they plunder the deep.

## **Unplumb'd, salt, estranging sea**

Most policymakers' first response to overfishing, if not to deny it, has been to extend their country's territorial waters. The “free seas” advocated by Hugo Grotius, a Dutch jurist, in 1609 never in practice extended quite to the high-tide mark. But from the 18th

century to the mid-20th, territorial waters, within which foreigners had no rights except that of “innocent” passage, ended three miles from shore.

In 1945, though, the United States unilaterally claimed jurisdiction over the natural resources of its continental shelf. Other countries followed suit, and some started to extend their territorial waters to 12 miles. Chile and Peru soon pushed their limits to 200, and other Latin American and African countries were not far behind. By 1958, Iceland, whose fishing catches were already diminishing, extended its limit to 12 miles too, and precipitated the first of three “cod wars” with Britain. Claims were everywhere being asserted, contested and copied. Order was needed.

After three conferences convened by the United Nations to draw up a comprehensive law of the sea, coastal countries today have territorial waters up to 12 miles from land in which they exercise total control except for the right of innocent passage. For the next 12 miles, ie, up to 24 from the shore, they have fewer rights but may also control customs, immigration and taxation. And up to 200 miles they have an economic zone with control over various maritime activities and the right to exploit natural resources under the seabed or on it, so long as these are fixed and do not move. This is about to be extended.

From the point of view of fish in coastal waters, this should have been good news: instead of belonging to everyone, ie, no one, they now have national owners with a clear interest in their preservation. As the evidence of continued overfishing shows, however, most of the owners have yet to find, or implement, the right policies.

A variety of remedies have been tried, usually in combination. Thus regulations have been issued about the size and type of fish to be caught, the mesh of nets to be used, the number of days a month that boats may go to sea, the permissible weight of their catch and so on. In some countries fishermen are offered inducements to give up fishing altogether. Those that continue are, at least in theory, subject to monitoring both at sea and in port. Large areas are sometimes closed to fishing, to allow stocks to recover. Others have been designated as marine reserves akin to national parks. And some of the technology that fishermen use to find their prey is now used by inspectors to monitor the whereabouts of the hunters themselves.

Most of these measures have helped, as the recovery of stocks in various places has shown. Striped bass and North Atlantic swordfish have returned along America’s east coast, for instance. Halibut have made a comeback in Alaska. Haddock, if not cod, have begun to recover in Georges Bank off Maine. And herring come and go off the coasts of Scotland. Those who doubt the value of government intervention have only to look at the waters off Somalia, a country that has been devoid of any government worth the name since 1991. The ensuing free-for-all has devastated the coastal stocks, ruining the livelihoods of local fishermen and encouraging them, it seems, to take up piracy instead.

But too often the recovery, if it comes, is partial or temporary. Pressure mounted to reopen Georges Bank for haddock as soon as the first signs of vigour returned, and limited fishing is now allowed. In some places, round the Channel Islands of southern

California, for instance, fish cannot thrive because their habitat—in this instance, the kelp forests—has been destroyed. Elsewhere the sea mounts, the hills and mountains that rise up from the ocean floor but do not break the surface, have been ruined by smash-and-grab trawlermen. In many places the rules are simply ignored. Illegal fishing thrives, landings go unmonitored, skippers keep two sets of logbooks, officials are bribed.

Often agreements are ignored as soon as they are signed. Several countries agreed, for instance, to cut Atlantic swordfish catches in 1991. Spain and America did so, but not others: Japan's catch rose by 70%, Portugal's by 120% and Canada's by 200%. France, Ireland and Italy were among the countries that continued to use large-scale drift nets on the high seas after they were banned by the UN in 1991. These nets, by definition over 2.5km long, indiscriminately scoop up enormous quantities of marine life: whales, turtles, dolphins, small fish of no commercial value, the lot.

Bycatch was not confined to drift-netting. In commercial fisheries as a whole, 25% of the catch was discarded in the 1990s. At the same time the use of fishing lines as long as 125km, whose thousands of baited hooks attracted diving seabirds as well as their intended prey, was calculated to be killing 40,000 albatrosses a year. Nets of one kind or another meant to catch Pacific yellowfin tuna were also killing 400,000 dolphins a year.

New methods of setting nets have reduced the bycatch of dolphins but not of other species, such as billfish, turtles and sharks. In his book, "The End of the Line", Charles Clover says that, for 15,721 tons of tuna, fishermen using these dolphin-friendly methods caught 237 tons of sharks and rays and 15,500 tons of other fish.

Sharks provide a particularly unhappy example of destruction. They have long been hunted in the Mediterranean and are now close to extinction there, having been reduced to 3% of their stock 200 years ago, according to Lenfest Ocean Program, an institute based in Washington, DC. They have not been much luckier in North America. Never quite as cuddly as polar bears or as lovable as porpoises, sharks became sinister objects of hatred after the publication of Peter Benchley's bestseller, "Jaws", in 1974 and the success of the film a year later. A guilt-ridden Benchley then became a marine conservationist and a campaigner for sharks in particular, but by that time many people's latent fears of Great Whites had turned into open loathing of all sharks, even the harmless, plankton-eating basking variety.

### **Oh, the shark has pretty fins, dear**

Still, the greater threat to sharks comes not from game fishermen but from Asian gastronomes whose idea of a treat is shark's-fin soup. For years sharks were caught chiefly for their fins; often, indeed, the fins would be cut off and the creature thrown back in the water alive, there to suffer a slow death by drowning. Nowadays, with at least 11 kinds of shark facing extinction and many more of the 400 species either vulnerable or endangered, sharks are to some extent protected. But the value of their fins, which rivals that of caviar, and the ease with which they can be hidden from inspections on a fishing-



boat keep the shark in perpetual danger. Perhaps 73m sharks are killed each year for their fins, and the number is rising fast. Spain and Indonesia are among the worst culprits, according to the International Union for Conservation of Nature.

Other fish are not faring much better. Eels are fast vanishing from the Mediterranean, swordfish from the Indian Ocean. The orange roughy, a slow-growing perch now marketed as emperour, was virtually fished out in British waters soon after trawlermen set their sights on it in 1991. It seems all but doomed almost everywhere except perhaps round New Zealand. The bluefin tuna faces “impending extinction” in the west Atlantic, according to Carl Safina, of the Blue Ocean Institute in East Norwich, New York, an example, he says, of “how management can go off track if the scientific part of the process is corrupted by short-term economics and political lobbying”.

All in all, the politicians charged with safeguarding the fisheries seem to be failing. Is nobody getting it right?

### **An Icelandic success**

*We have to prove to the rest of the world that “the fish can sing just like a bird”.*

Halldor Laxness

ICELAND has not quite proved that fish can sing, but it has shown they can continue to flourish, even when hunted by their main predator, man. Central to its policy are the individual transferable quotas given to each fishing boat for each species on the basis of her average catch of that fish over a three-year period. This settles the boat’s share of the total allowable catch of that fish for the entire country. The size of this total is announced each year on the basis of scientific advice from the independent Marine Research Institute.

Subject to certain conditions, quotas can be traded among boats. Bycatch must not be discarded. Instead it must be landed and recorded as part of that boat’s quota. If she has exhausted her quota, she must buy one from another boat, though 20% of a quota may be carried forward a year, and 5% of the next year’s quota can be claimed in advance. Gadgets carried on all vessels send electronic signals to make satellite monitoring possible at all times, and each boat is likely to go to sea with an inspector aboard twice a year. All catches are rigorously recorded as soon as they are landed at any of the country’s 53 ports or by Icelandic officials abroad. So the Marine Research Institute knows exactly how much each boat is catching and where. It claims that 95% of the total is well reported.

Technology helps the fishermen, too. By looking at the Directorate of Fisheries’ website they can see all landings by date and species and thus work out whether to sell their catch

fresh or frozen, and whether to buy, sell or carry forward quotas. All quota changes, catches and landings are posted on the internet, enabling everybody to see what is going on. The idea is to let fishermen be guided by the market.

Boats are not restricted as to when they can fish. Limits used to be placed on the number of days per month a boat could spend at sea. That led to overfishing. Some boats now fish for only three months a year, after which their quotas are full.

A main objective is to protect spawning and young fish. Some grounds are closed during the spawning season (eg, for cod); others—nursery areas—are permanently off limits. Bottom trawlers are banned from fishing within the 12-mile limit, and inspectors can instantly close any area for a fortnight or more if they think it is being overfished. In 2007 there were 180 closures, a record, largely because of an influx of young haddock.

The system is not perfect. In Iceland, as elsewhere, fishermen and scientists can disagree, and the total allowable catch is set by a minister who sometimes yields to political pressure. Cod is far and away Iceland's most valuable fish, but its stocks are falling: the tonnage caught since the 1990s has been about 200,000 a year, compared with about 400,000 in the 1960s. The mean weight of fish caught is also dropping, which worries the research institute greatly, though the biomass of spawning stock has increased slightly since 1985.

Newcomers to the industry find it hard to buy the licences and quotas they need to start fishing. As a result, the number of boats is falling. Yet Iceland no longer suffers from overcapacity, and the catch per boat is increasing. Ownership, however, is growing more concentrated.

Most of Iceland's fish are caught within its 200-mile exclusive economic zone. Few foreign boats are allowed in these waters, and none can buy Icelanders' quotas. But Iceland has an interest in fish whose stocks may live partly within and partly outside its limits, or may migrate; and many of its boats also fish outside their own waters, mostly in the north-east Atlantic. Three international agreements govern fishing in these seas, all managed by the North-East Atlantic Fisheries Commission, based in London. One concerns herring, signed by Iceland, Norway, Faroe, Russia and the EU. The other two, with fewer signatories, control blue whiting and mackerel. All seem to work well, though illegal fishing, mostly by ships sailing under frequently changed flags of convenience, remains a problem.

Iceland offers lessons for other countries. The essential elements of its policies are to give fishermen rights that offer a reasonable expectation of profitable long-term fishing by encouraging the conservation of stocks. The system is clear, open and fairly simple, and it is well policed. It thus enjoys the respect of fishermen. And it is based, crucially, upon scientists' assessments of stocks, not politicians' calculations of electoral advantage.

### **A trout in the milk**

This contrasts with the common fisheries policy of the EU, whose members' 88,000 boats together catch about 5m tonnes of fish a year. This puts the EU second only to China as a fishing power. For years, the union has simultaneously discouraged and promoted fishing, even as stocks have declined. Overfishing has intensified and the overcapacity of the fleet a few years ago rose to the point where the number of boats was almost twice the number needed for a sustainable harvest. The EU has offered inducements to those who gave up fishing even as it provided subsidies for such objectives as the "modernisation" of national fleets. Modernisation aid supposedly ended in 2005, but the union's fisheries fund, which supports everything from aquaculture and sustainable development to the "adjustment" of the fleet, is set to spend €4.3 billion in 2007-13. Spain, the most voracious piscivore and the biggest recipient of aid, will get €1.13 billion.

The EU's fisheries policy has long been notorious for its destructiveness, epitomised by the practice it either mandates or encourages of chucking back dead fish that are not big enough or not valuable enough, or just the wrong sort. It is a main reason that Iceland and Norway, two countries serious about the sea, have not joined the club. Just over a year ago the EU's own Court of Auditors drew attention to some of the reasons the policy is so disastrous. The extent of cheating (by fishermen) and lying (often by national governments) was so great that no one really knew the size of the total catch. The states themselves were meant to police the system, but offenders were seldom caught and those who were usually received little or no punishment. Few countries came out well. Off the record, officials described Poland as "bad", Italy "really bad", Spain notorious for hiding fish and using illegal nets, Scotland not much better. No wonder the EU's stocks are 88% overfished, as the European Commission itself now admits.

In few EU countries is fishing economically crucial. Nowhere does it account for even 1% of GDP, and as a source of employment its importance is only local, though often that is in places where other jobs are scarce. The upshot is that fishermen exercise great weight as a lobby. The hardship of their job earns them some public sympathy, though life on today's trawlers, high-tech vessels fitted out with all mod cons, is very different from that on the boats of a few decades ago. And they can be ruthless in pressing their case, as shown by their frequent demonstrations, such as those in Brussels last June. On that occasion, the fishermen wanted subsidies for their fuel, though they already get the stuff tax-free.

In Joe Borg, the EU does now have a fisheries commissioner who is serious about conservation, but the basic flaws in the system remain. Science is disdained. The scientists' proposals that precede the annual allocation of quotas are routinely expanded, first by the commission and then by the ministers. They often end up 50% higher than recommended, and are then usually disregarded by rapacious fishermen. As in most EU meetings, the ministers all speak for the same lobby, in this case the fishermen. No minister is present to represent the taxpayer, the consumer or the environment, let alone the fish.

Adding to the scandal is the way that Europeans, having largely destroyed their own fisheries, are now setting about those of others. The cry for subsidised fuel arises largely because European boats must travel ever farther to find fish (as a general rule, it takes nearly half a tonne of fuel to catch one tonne of fish). Not content with the high seas, the EU now has deals to “access surplus fish resources” in the waters of about 15 small countries from Cape Verde to Micronesia and the Solomon Islands, via Madagascar and the Comoros. Pundits are dispatched regularly to lecture the locals about responsible fishing. Out to the west of the Maldives, however, to take but one example, French and Spanish boats can be seen dragging purse-seine nets up to a mile long in pursuit of tuna, and at the same time indiscriminately scooping up turtles, dolphins and other creatures, many endangered, many doomed to die.

### **Fishing up the moon**

Europe could surely learn from Iceland, but how widely could Iceland’s policies be copied? In most of the few places that enjoy a good reputation for looking after their fisheries—including Alaska, New Zealand, Norway and Namibia—fishing is economically or socially important. For Iceland it provides some 12.5% of GDP and 7% of employment. In many poor countries, however much they may depend on the seas for protein, conservation takes second place to hunger—or unwise international fishing agreements, sometimes corruptly negotiated. In some rich countries, such as Japan and Spain, demand for fish is vastly greater than local supply, encouraging fishermen to pillage the world’s seas. And in many rich countries fishing communities, though hardly populous, exert concentrated lobbying power that overwhelms the diffuse interests of the majority.

In Europe, it is tempting to argue that country A will never behave responsibly in the waters of country B, and so the idea of a common policy that allows all 27 members, even landlocked ones, the right to fish in each other’s seas is a recipe for devastation. Yet overfishing did not begin with the EU’s common policy, and even Icelanders would overexploit their waters if not restrained.

The solution for Europe, and for other places, lies in a policy with Icelandic features: transferable quotas for all commercial species, each with a total allowable catch; strict enforcement of the rules and open access to all relevant information about landings and so on; severe punishment for malefactors, including fines, the suspension of licences, the confiscation of tackle and even imprisonment, as in Iceland. It is also essential to have good scientific information, and to respect it.

Scientists, however, do not have a monopoly of wisdom about the sea, and no system will work well if it excludes the knowledge of fishermen, ignores their economic well-being or depends on the fear of sanctions to obtain their co-operation. The trick is to persuade them that their long-term interest, which coincides with that of the fish, trumps their short-term one, which is to extract the last minnow as quickly as possible.

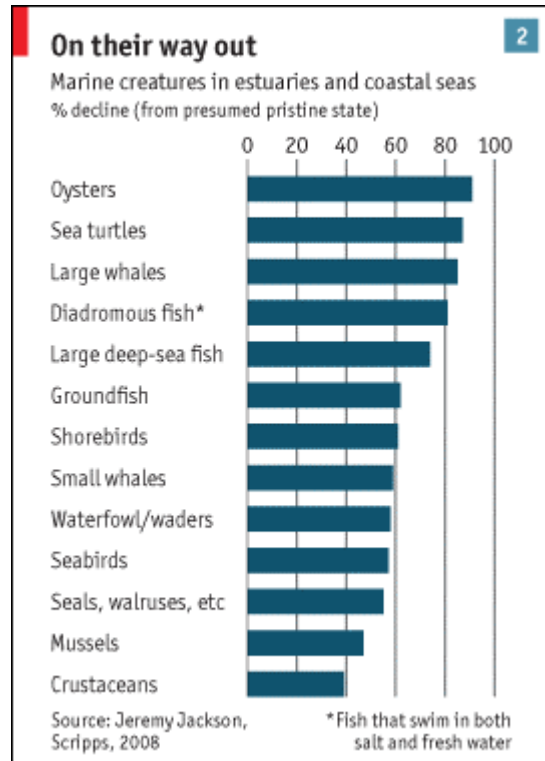
Property rights are nearly always crucial in this. The tragedy of the sea is the tragedy of the commons, which is that anyone with access to a common resource has an interest in over-exploiting it because if he does not, someone else will. The high seas, which remain common, though subject to the UN Convention on the Law of the Sea's injunction to conserve their "living resources", present the biggest difficulties. That is why the outlook for the big, slow-growing creatures of the deep, some of which travel long distances, is so bleak.

Most fish, however, live fairly close to land, which is where they can, if the political determination exists, be assigned to the ownership of people with an interest in both exploiting and preserving them for a very long time, if not eternity. That this is so has been shown by Christopher Costello, an economist at the University of California, Santa Barbara, and his colleagues, in a study of over 11,000 fisheries. In the 121 with ownership-share systems, he reported in *Science* last September, the rates of collapse were significantly lower than in the others. That may not reveal much about the rates of recovery, but with fewer collapses, recoveries would become less necessary. Assigning ownership rights to locals has also proved a successful way of preserving coral reefs.

Such rights can be created by government fiat in territorial waters, but George Sugihara, a scientist at Scripps who spent five years as an investment banker, believes they can, and will, be created in a more evolutionary way.

He likes to compare fisheries to banking, both parts of essentially unstable ecosystems whose workings are only partially understood. In both, there is a need to manage risk and uncertainty, especially since the periodic upheavals can be profound. In both, people are tempted to look at the parts rather than the entire ecosystem—Georges Bank in fishing, says Dr Sugihara, Deutsche Bank in banking. Yet the context is important.

Fisheries differ from banking, though, in that the markets for fish are unsophisticated, lacking both futures and options. Indeed, fish is the only widely traded commodity that has no derivatives market. Yet derivatives could be devised that would promote sustainability. Pollution credits, for example, could be traded if fishermen had transferable quotas. At present, if too many turtles are inadvertently caught in Hawaiian waters, the entire fishery is closed down. Allocate credits for the total acceptable number, and they could be traded. Forward credits could be useful in the squid business. If a



fisherman sold the squid processors a proportion of his expected catch a year ahead and squid turned out to be plentiful, he would do well. If they were scarce, he could sell his contract and turn instead to sardines or anchovies. This would prevent overfishing of squid. The processors, believes Dr Sugihara, would get a clear, open market, preferable to the opaque system that operates in most places at present.

With a new market, new regulations would follow. In time, the idea would spread. Thus the price fluctuations that come with boom and bust, and encourage overfishing, would be smoothed out. The fundamental problem, Dr Sugihara argues, is the management of risk.

### **Saline solutions**

*For while the tired waves, vainly breaking,  
Seem here no painful inch to gain,  
Far back through creeks and inlets making  
Comes silent, flooding in, the main.*

Arthur Hugh Clough

IS IT too late to save the sea? The solutions to some of its problems are fairly clear, even if it requires political courage to put them in place; overfishing is an example. Others are more uncertain. No one fully understands coral reefs—whether corals expel or are deserted by the single-cell algae that live within their polyps' tissues, for instance—still less what will happen to any given ecosystem if something is taken out of it. Much more research is needed in several disciplines. Many more voyages of discovery are also needed, especially in the vast expanses of the southern seas that remain relatively unexplored.

To ask whether the sea can be saved may, however, be to pose the wrong question. It is not going to disappear: rather the opposite. But that does not mean it is safe, nor even that it can strictly be saved, in the sense of returned to some pristine pre-industrial state, not at least for thousands of years. It is going to be changed, come what may, and the questions are more about how it will be changed and how marine and other life will adapt.

Again, many of the answers are unclear. Will calcium-carbonate-shelled creatures adjust or die as the ocean grows less alkaline? Will hurricanes grow more or less intense as the seas grow warmer? Will changes in the circulation of the depths warm and destabilise the hydrates on the seabed, releasing quantities of greenhouse gases from their deep-sea prisons?

Some people are inclined to dismiss such questions as alarmist. The sea is vast. It has a limitless capacity to absorb and adjust, they say. Man cannot afford to devote huge quantities of energy and money to changing his ways simply to assuage general worries

about uncertain possibilities. And the exact contributions of man and nature to the changes taking place are surely unknown, even if it is accepted that man is making natural cycles more pronounced. Moreover, human ingenuity can be relied on to come to the rescue: carbon can be captured, green fuels will become economic, the sea itself can be engineered to absorb all man-made CO<sub>2</sub>.

Well, maybe, Mr Micawber. But if not, the costs could be great. Indeed, even continuing on the current course will be expensive. In the lifetime of people already born, vast amounts will have to be spent on protection from rising sea levels. The alternative will be to abandon many large cities; Kolkata (Calcutta) is probably the most vulnerable to the incoming tides, but New York's subway system would be flooded with a rise of only 80cm. At least part of the costs of clearing up after storms like the ones that struck New Orleans and Mumbai in 2005, Bangladesh in 2007 and Myanmar in 2008 should probably be put down to warming seas.

### **Is it for you to ravage seas and land?**

As for fishing, it needs to be better managed to take advantage of the huge opportunities for feeding a growing world. Fish are already the main animal protein for over 1 billion people and provide the livelihood for 200m people, 90% of them in poor countries. Developing states cannot afford to ruin their fisheries the way that richer countries have. In California, where sardines, mackerel and tuna were once the staples of the fishing industry, three of the five most valuable catches are no longer fish but squid, crabs and sea urchins.

If nothing else, the risks of continuing on current paths need to be recognised and then managed. It will take time to answer the big questions: why so many changes are happening so fast; whether abrupt, extreme events like cyclones and ice melts will lead to a cascade of other events; how cause and effect interact in complex ecosystems where small changes may be synergistically amplified.

In the meantime some practical measures must be taken. Above all, it has become plain that the absence of ownership does not make for good management. The sea needs owners, and where that is impossible it needs international agreements for regulation, management and policing. Peru, whose anchoveta fishery is the largest in the world, is coming round to a rights-based approach to fishing, as are some African and South-East Asian governments. Countries such as China, India and South Africa are becoming increasingly interested in safeguarding marine resources. And organisations such as the Pew Oceans Commission are producing excellent policy recommendations.

But more international co-operation is needed and the EU, with 68,000km of coast and an unseemly appetite for the world's fish, needs to take conservation much more seriously. The UN Convention on the Law of the Sea can provide a framework. America should ratify it as soon as possible, and then help mobilise a consensus to take care of the 71% of the planet covered by water. The risks of doing nothing are just too frightening.