The Economist

SPECIAL EDITION

PLANETARY HEALTH

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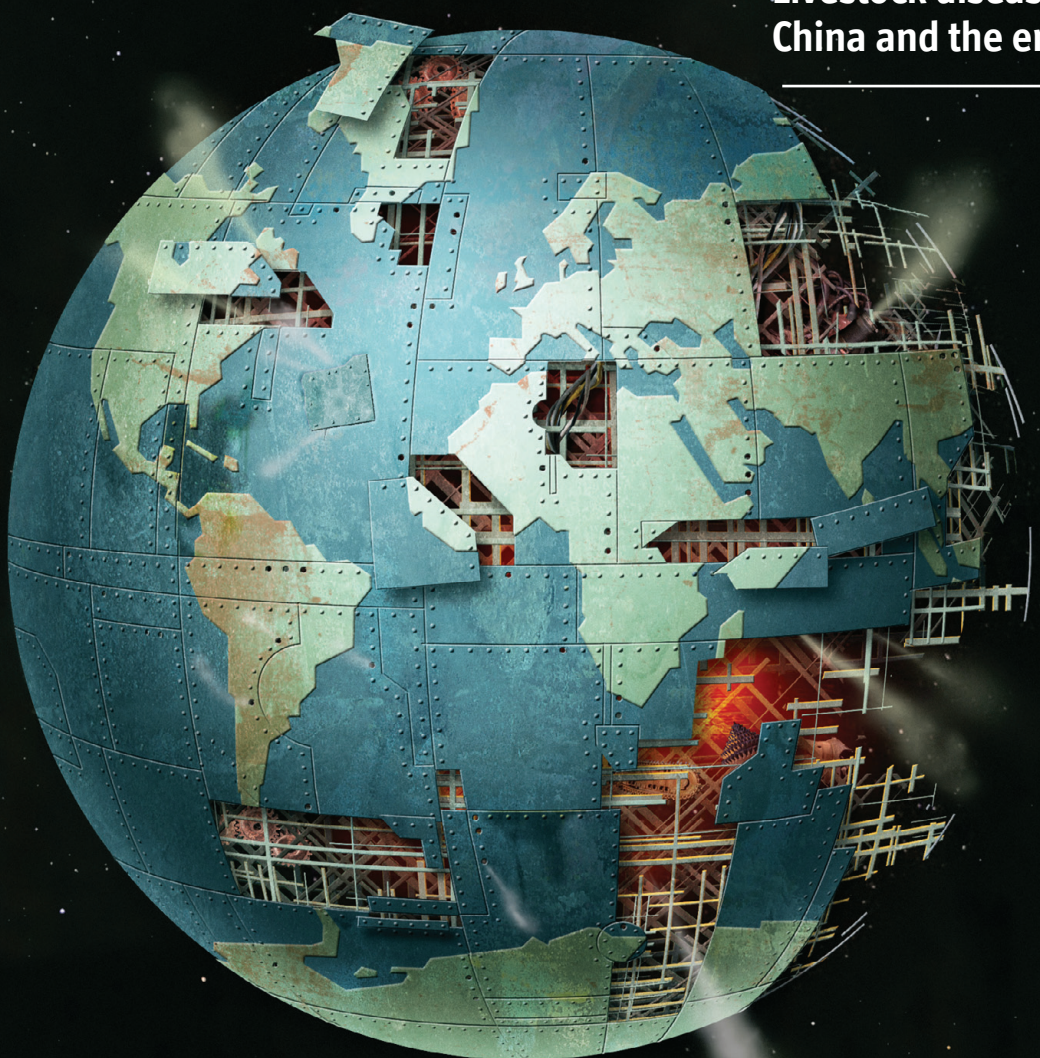
In this issue:



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Planetary Health:

Improving Well-being, Protecting Ecosystems, and Sustaining Human Civilisations

In 2013, Martin Rees, former president of the UK's Royal Society, a prestigious fellowship of scientists from every field across science, engineering and medicine, wrote in *Science* magazine, "The main threats to sustained human existence now come from people, not from nature. We have a limited time base for exposure to [these threats] and can't be so sanguine that we would survive them for long, or that governments could cope if disaster strikes."

The first part of Rees's statement is uncontroversial. It is widely agreed that we live in an anthropocene era, one in which human activities are perceived to impact our planet's ecosystems unfavorably. But the second part is more alarming. Here, he suggests that our ability to escape these threats may be limited. Dangers humans face may not be resolved by adapting to or lessening the harm wrought by our activities. Rees is describing the ultimate threat to human health—our species' extinction by our own hand.

Yet there is a paradox in this predicament. In the past decade, driven mostly by the United Nations' Millennium Development Goals (MDGs)—eight goals for 2015, agreed to by all the world's countries, including halving poverty and improving maternal and child health—a powerful new discipline deeply concerned with human health and well-being known as "global health" has emerged. This intense concern with our well-being is reflected in an astonishing increase in Development Assistance for Health (DAH), or development-focused funds for health from public and private institutions for low- and middle-income countries.

Before the MDG era (pre-2000), annual growth in DAH was 5.9%. In 2001, total DAH stood at $10.8bn. But from 2001 onwards, annual DAH growth accelerated as high as 11.2% for DAH that totaled US$28.2bn by 2010.

Shifts in research or policies often reflect the concerns of particular times and places. Such is the case with global health. Global health has emerged at a moment when the risks and drivers shaping the health of populations cross national borders in entirely new ways, evident in global epidemics and the increasingly common causes of non-communicable diseases, such as smoking and obesity. The complex and intertwined nature of global health thus suggests an interest in trans-border health issues and solutions, interdisciplinary study and the integration of public health with the multiple dimensions of health care.

Global health is an improvement over the concept that preceded it: international health. The word 'global' implies a commitment not only to improving health, but also to achieving equity among peoples. Because the concept suggests that individuals and populations are interdependent, global health also demands revisiting the political, economic and social contexts of health and disease.

Indeed, understanding our current challenges and finding solutions to them will require far deeper levels of collaboration between peoples. The values that underpin global health have created a new generation of activism for a healthier and more equitable world.

But is global health—in both its definition and scope—truly meeting the demands that our societies currently face? One could argue that global health may still be too narrow to explain and illuminate some pressing challenges today. Global health does not fully take into account the natural foundation on which humans live—the planet itself. Nor does it factor in the force and fragility of human civilisations.

Our planet is under increasing pressure, not just from the 2bn more people who will inhabit it between now and 2050. That is why the post-MDG era is focused on sustainability, or the idea that not only are human and natural systems interdependent, but also that the deviation of environmental trajectories from their natural course could be catastrophic. In this way, the goals of sustainability differ greatly from those that have dominated the MDG era. Sustainability means valuing tomorrow as much as today because the planet's potential to sustain the human species is slowly declining. It means being concerned about all of us, not just some of us. Clearly, the post-2015 era's most important idea is that global sustainability is the bedrock of human health, survival and prosperity.

To more precisely define what it is we must sustain, Johan Rockström, a professor of Environmental Science at Stockholm University, introduced the concept of planetary boundaries, or the idea that our species must live within a safe operating space. That space is defined by dangers such as ocean acidification, ozone depletion, declining freshwater resources, biodiversity loss, chemical pollution and climate change. If one or more of these boundaries is breached, environmental trajectories that veer from their natural path could impact planetary systems so severely that the very survival of the human species would be in jeopardy. Already, Rockström argues, three planetary boundaries have been crossed—those of climate change, biodiversity and the global nitrogen cycle.

Since its 2009 introduction, this planetary-boundary approach has captured the imagination of many scientists and policymakers. But another dimension should also be considered. Planetary boundaries focus on our planet's natural systems and how human activity is changing them. But what about human systems—the political, economic, social, technical and environmental policies and institutions we create, which together shape the decisions and actions that affect our planet's natural systems? In other words, what about human civilisations, and how they impact our future? And how will that future, in turn, affect human civilisations? One could argue that the way we organise society's decisions and actions to face planetary threats is more important than the threats themselves.

Consider these questions: What risks do our civilisations face, and how will we identify them? Are we living through a key transition for our species and civilisations, and how would we know if we were? What forces have shaped past civilisations and our civilisations today, and what will protect future civilisations? What will determine human sustainability and resilience in the face of these planetary dangers? Is human and planetary sustainability compatible with our current expectations for economic growth and material prosperity?

To answer these and other questions, The Lancet and The Rockefeller Foundation are launching a commission and convening a major global gathering at the Foundation's Center in Bellagio, Italy. This special edition of *The Economist* magazine will, together with other inputs, help shape that ongoing conversation.

This commission and the July 2014 Bellagio Center meeting will investigate the threats to human civilisations from planetary-system disturbances and explore a wide range of possible responses to those threats. It will argue that we need to go beyond even the broad manifesto of global health, by instead adopting a whole-planet (planetary) view of human health and well-being. It will describe the nature of the systems affecting planetary health, define the goals of securing planetary health, suggest a roadmap for achieving these ambitious objectives and propose concrete actions to do so. Finally, the commission will seek to identify the concepts, methods and tools necessary to prevent civilisational collapse, and to foster the flourishing of human societies. ■

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The global environment

Boundary conditions

Reprinted from The Economist, Jun 16th 2012

The idea of planet-wide environmental boundaries, beyond which humanity would go at its peril, is gaining ground

PULL a spring, let it go, and it will snap back into shape. Pull it further and yet further and it will go on springing back until, quite suddenly, it won't. What was once a spring has become a useless piece of curly wire. And that, in a nutshell, is what many scientists worry may happen to the Earth if its systems are overstretched like those of an abused spring.

One result of this worry, in the autumn of 2009, was the idea of planetary boundaries. In the run-up to that year's climate conference in Copenhagen a group of concerned scientists working under the auspices of the Stockholm Resilience Centre, in Sweden, defined, in a paper in Nature, what they thought of as a safe operating space for human development—a set of nine limits beyond which people should not push their planet.

The nine areas of concern were: climate change; ocean acidification; the thinning of the ozone layer; intervention in the nitrogen and phosphate cycles (crucial to plant growth); the conversion of wilderness to farms and cities; extinctions; the build up of chemical pollutants; and the level of particulate pollutants in the atmosphere. For seven of these areas the paper's authors felt confident enough to put numbers on where the boundaries actually lay. For chemicals and particulates, they deferred judgment.

Since then, the idea of planetary boundaries has taken root. It crops up repeatedly in GEO-5, the United Nations Environment Programme's new assessment of the world. The High-Level Panel on Global Sustainability, which reported recently to Ban Ki-moon, the UN's secretary-general, gave the idea pride of place. And Planet Under Pressure, a big scientific conference held recently in London, made boundaries central to the message it sent to Rio+20, the UN environmental summit that opens in Brazil on June 20th.

Don't fence me in

Planetary boundaries provide a useful way of thinking about environmental change, because in many cases they give scope for further change that has not already happened. That has brought the concept friends who are not normally persuaded by environmental thinking, as well as green enemies who will brook no compromise. But the concept has numerous drawbacks. The actual location of the boundaries is, as their proponents acknowledge, somewhat arbitrary. That is partly because of the incomplete state of current knowledge, but it may remain so however much anyone knows. Some boundaries might be transgressed without irreversible harm occurring. Some may have been drawn around the wrong things altogether. And some academic opinion holds that spectacular global change could come about without breaking through any of them.

The latest criticism comes from the Breakthrough Institute, a determinedly heterodox American think-tank that focuses on energy and the environment. Among the points made in a report it published on June 11th, two stand out. The first is that the idea of boundaries does not focus enough on the distinction between things with truly global effects and those that matter primarily at a local or regional level. The second is that the planetary-boundaries group derives most of its limits by looking at conditions during the Holocene—the epoch since the end of the most recent ice age, in which human civilisations have grown up. Both of these criticisms have merit.

For things that clearly do have the springlike quality of shifting irreversibly if pulled (or pushed) too far, like the collapse of ice sheets or the melting of permafrost, a boundary system that seeks to stop you getting too close to the threshold seems as sensible as a safety rail is on a parapet. There is good reason to believe that parts of the climate do behave this way, and thus need railing off. But of the nine boundaries, only three apply to systems where the boundary setters really believe there is a global threshold: the climate; the acidity of the oceans; and the ozone layer. Some of the other six may have local thresholds, but for the most part their global effects are simply the aggregate of the local ones.

Confusing the two might, in the Breakthrough Institute's view, result in poor policy. Concern over a planet-wide nitrogen limit, for example, could lead to people forgoing the benefits that fertilisers offer the poor soils of Africa on account of harm done by their over-application in China.

The institute's other criticism is the implicit assumption that because mankind came of age in the Holocene, therefore Holocene conditions are optimal for the species now. There are indeed reasons to believe some aspects of the Holocene were optimal. It was a time of climatic stability and, in the temperate regions of the Earth, clemency. The Breakthrough criticism agrees that climate stability is a good thing. It points out, though, that there is little evidence things like the behaviour of the nitrogen cycle or the phosphate cycle in the Holocene were particularly well-suited to humans. The fact that people have used industrial chemistry to short-circuit the nitrogen cycle, by making fertilisers out of nitrogen in the air at a rate which greatly exceeds what natural systems can manage, has real environmental effects. Nitrate-rich run-off, for example, can wreck the ecology of lakes. But if these effects could be managed, then it is not clear that the amount of nitrogen being drawn out of the air would, of itself, be a problem.

This is, at bottom, an argument about the nature of the Anthropocene—the age of man. Many scientists feel that human interference in the way the Earth works is now so great that the Holocene is history and a truly separate Anthropocene has dawned. The planetary-boundaries idea seeks to constrain the Anthropocene within the norms of the Holocene. The Breakthrough Institute, by contrast, argues for ordering things according to a calculation of the needs of human welfare, rather than just aping what has happened in the past. There is no doubt as to which of the two approaches is more prudent, and prudence always has a constituency. There is plenty of room for debate as to which is more plausible, or practical.

Independence declaration

Another problem for the idea of planetary boundaries is the assumption that they are independent of each other. That seems unlikely, and if they are not then a crisis might arise even if no single boundary were transgressed. On June 7th Nature, which likes to get its oar in before big international powwows like the ones in Copenhagen and Rio, published a review of evidence that this may be happening. It suggested that the Earth may be approaching a "tipping point" past which simultaneous changes—to land use, climate and more—driven by an ever larger, ever richer human population, push the system into a very different state from its present one, with climate zones changed permanently, ecosystems functioning differently, and so on.

A sudden shift is plausible. Small ecological systems, such as lakes, often switch states in this way and there is no obvious reason why a large system like the Earth should not do likewise. And according to Anthony Barnosky of the University of California, Berkeley, one of the Nature review's main authors, a combination of changes, each itself within the planetary boundaries, could still trigger such a change of state.

That would be a bad thing. Even if the ultimate result were an Earth that is still hospitable to mankind, the transition could be catastrophic. But the existence of plausible bad futures within the boundaries raises the obverse question: are there good futures outside them? In particular, might it be possible to finesse the most famous boundary of all, the one governing greenhouse warming and climate change?

The planetary-boundaries team, slightly confusingly, defines this boundary in two different ways. One is a limit on carbon dioxide, the main long-lived greenhouse gas, of 350 parts per million (ppm) in the atmosphere. The other is a limit on "radiative forcing"—the increase in energy delivered to the surface of the Earth over time, largely as a consequence of extra greenhouse gases—of 1 watt per square metre above pre-industrial levels. Either way, the climate boundary is one that already lies squarely in humanity's rear-view mirror. This reflects the view of some on the planetary-boundaries team, such as James Hansen of the Goddard Institute for Space Studies, that today's climate is already beyond the point which can guarantee long-term survival for things like the Greenland ice sheet, the demise of which would raise sea levels by seven metres.

If the planetary-boundaries scientists really have got their sums right, the greenhouse-gas situation looks hopeless. From today's position of carbon-dioxide levels pushing 400ppm and going up about 2ppm a year, a carbon-dioxide level of 350ppm can be reached only by going to zero emissions and then spending a long time—centuries, in all likelihood—sucking CO_2 out of the atmosphere and putting it back underground by various means.

Force majeure

Greenhouse gases are, however, only a problem because of their effect on radiative forcing. If that could be reined back inside the boundary by other means, then the CO_2 limit would no longer pertain. And that might be possible by spraying reflective particles into the upper atmosphere, to bounce sunlight back into space.

Such a radical scheme would have all sorts of disturbing side effects, with political ones quite possibly outweighing environmental ones. It is by no means clearly the right thing to do. But it might be. And it certainly serves to show that, although the Earth may have boundaries, thinking about how to help it should not. ■

The outlook

Averting the sixth extinction

Reprinted from The Economist, Sep 14th 2013

Growth is good, but governments need to continue to regulate it and greens to learn to love it

OVER THE GRAND sweep of history and geography, things have not been going well for Earth's non-human species. Extinction rates over the past few centuries have been far higher than the background rate, and taking the world as a whole the picture over the past few decades has been looking pretty bleak. The Living Planet Index shows a 30% decline in biodiversity since 1970.

Take a closer look, though, and a more optimistic account of the planet's trajectory emerges. What limited information on extinctions is available suggests that trends have improved recently. Although the LPI shows a global fall in biodiversity, and a stark decline in poorer countries, in richer countries conditions are improving for other species. That is thanks to the developments covered in this special report—shifting public attitudes to other species, increasing appreciation of natural environments, legislation to stop the killing of endangered species, programmes to eradicate invasive species, more and bigger protected areas for wildlife, subsidies to restore degraded habitat, better sanitation, better regulation of pesticides, decreasing levels of conflict and increasingly effective states implementing conservationist legislation. All of these become more prevalent as countries get richer.

Yet the survival of most of the planet's remaining non-human species is by no means assured. Leaving aside the huge unknown of climate change, whether or not the sixth great extinction is looming depends largely on what happens to growth and how humanity manages that growth.

Faster growth will mean higher consumption of resources and more pressure on habitat, which is bad for other species. But as North Korea's experience shows, the combination of economic stagnation and poverty is even worse. Growth can benefit biodiversity, so long as it is combined with regulation and investment to protect other species. That has happened to some extent; whether it happens enough to prevent biodiversity being drastically reduced depends largely on governments in emerging markets.

But the biggest question of all for other species is what happens to land use. With habitat loss the principal threat to biodiversity, and agriculture taking up two-fifths of land compared with 3% for urban areas, the demand for food, and how it is met, will determine how much land is left for other creatures.

According to research led by David Tilman of the University of Minnesota, demand for food is likely to double by 2050. The UN's central estimate is for the world's population to rise by a third over that period, from 7.2 billion to 9.6 billion, but demand for food will grow faster than that, because as people get richer more of them will get enough to eat and more will be able to afford more meat. Meat consumption per person in China has risen from 4kg a year in 1961 to 58kg in 2009. In Britain it is 84kg.

Assuming that current levels of wastage persist, if demand for food were to double and crop yields remained the same, the amount of land cultivated would need to double as well. Since around 40% of the land on the planet is already cultivated, that would not leave much room for other creatures. But if farming were to become twice as productive, there would be no need to till any more land. Over the past 60 years America's corn farmers have done better than that: production has quadrupled on an area that has increased by half (see chart).

Loaves and fishes

For agriculture to pull off the same trick again would mean either boosting yields in high- ▸▸

Looking for a high-tech solution

yielding countries yet further or intensifying agriculture in low-yielding countries. The first may be hard to do: agricultural tech companies are struggling to get any more yield out of cereals growing in favourable conditions. But there is clearly scope for the second. In America, for instance, corn (maize) yields are around 7.7 tonnes per hectare, compared with 2.5 tonnes in India.

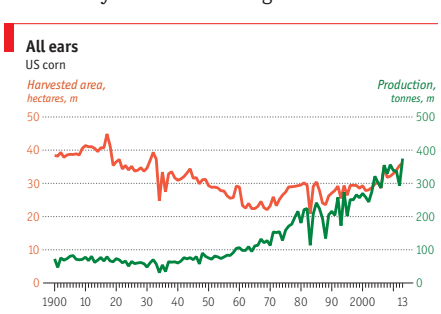
Boosting yields means using more fertiliser, pesticide and GM seeds. Some environmentalists understand this, but few publicly support the intensification of agriculture. Attitudes to GM among the big NGOs range from the RSPB ("maintains an open mind") and WWF ("precautionary approach") to Greenpeace ("a serious threat to biodiversity and our own health") and Friends of the Earth ("unnecessary risks to both humans and nature"). Among green political activists, hostility to the intensification of agriculture is near-uniform. In consequence, GM seeds are, in effect, banned in the European Union (though EU citizens feast on GM products freely imported from other countries) and rich-world activists have exported their opposition to GM crops to Africa and Asia.

Hostility to intensive agriculture within the green movement is understandable. Environmentalism was partly a response to "Silent Spring". Opposition to companies like Monsanto and Syngenta is bred into the green movement. So is hostility to growth: environmentalism's roots lie in the Romantic movement that sprang up in opposition to the industrial revolution. Deep in the green movement's soul lies a belief that the wrongs done to the planet were caused by technological change and economic growth, and that more of them can lead only to greater evil.

It is true that if man had never sharpened his first spear, the mastodons would probably still be roaming the plains of North America and the aurochs the grasslands of Europe. But it is wrong to conclude from this that more growth and more technological change would compound the disaster. For the first time since he got the upper hand, it looks as though man may succeed in averting the sixth great extinction, for a series of interconnected reasons.

As mankind has got richer, he has set about cleaning up some of the mess that he has made of his surroundings. Growing prosperity has induced him to care about matters beyond his own survival and that of his tribe and to translate those concerns into laws, regulations and programmes, both publicly and privately funded, that have changed people's behaviour towards their environment. At the same time, the technological progress that has accompanied economic growth has not just made conservation more effective but has also enabled man to produce more of what he wants from less, to the benefit of other species.

Many in the environmental movement regard economic growth and technological progress as enemies of biodiversity. Actually, they are its friends. Only through more of both can man hope to go on enjoying the company of the 8.7m or so other species with which he was born to share this planet. ■



Climate science

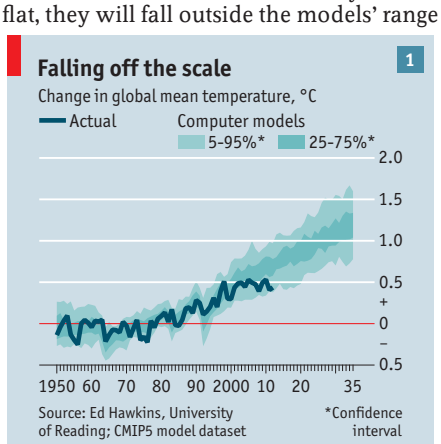
A sensitive matter

Reprinted from The Economist, Mar 30th 2013

The climate may be heating up less in response to greenhouse-gas emissions than was once thought. But that does not mean the problem is going away

OVER the past 15 years air temperatures at the Earth's surface have been flat while greenhouse-gas emissions have continued to soar. The world added roughly 100 billion tonnes of carbon to the atmosphere between 2000 and 2010. That is about a quarter of all the CO_2 put there by humanity since 1750. And yet, as James Hansen, the head of NASA's Goddard Institute for Space Studies, observes, "the five-year mean global temperature has been flat for a decade."

Temperatures fluctuate over short periods, but this lack of new warming is a surprise. Ed Hawkins, of the University of Reading, in Britain, points out that surface temperatures since 2005 are already at the low end of the range of projections derived from 20 climate models (see chart 1). If they remain flat, they will fall outside the models' range



within a few years.

The mismatch between rising greenhouse-gas emissions and not-rising temperatures is among the biggest puzzles in climate science just now. It does not mean global warming is a delusion. Flat though they are, temperatures in the first decade of the 21st century remain almost 1°C above their level in the first decade of the 20th. But the puzzle does need explaining.

The mismatch might mean that—for some unexplained reason—there has been a temporary lag between more carbon dioxide and higher temperatures in 2000-10. Or it might be that the 1990s, when temperatures were rising fast, was the anomalous period. Or, as an increasing body of research is suggesting, it may be that the climate is responding to higher concentrations of carbon dioxide in ways that had not been properly understood before. This possibility, if true, could have profound significance both for climate science and for environmental and social policy.

The insensitive planet

The term scientists use to describe the way the climate reacts to changes in carbon-dioxide levels is "climate sensitivity". This is usually defined as how much hotter the Earth will get for each doubling of CO_2 concentrations. So-called equilibrium sensitivity, the commonest measure, refers to the temperature rise after allowing all feedback mechanisms to work (but without accounting for changes in vegetation and ice sheets).

Carbon dioxide itself absorbs infra-red at a consistent rate. For each doubling of CO_2 levels you get roughly 1°C of warming. A rise in concentrations from preindustrial levels of 280 parts per million (ppm) to 560ppm would thus warm the Earth by 1°C. If that were all there was to worry about, there would, as it were, be nothing to worry about. A 1°C rise could be shrugged off. But things are not that simple, for two reasons. One is that rising CO_{2_2} levels directly influence phenomena such as the amount of water vapour (also a greenhouse gas) and clouds that amplify or diminish the temperature rise. This affects equilibrium sensitivity directly, meaning doubling carbon concentrations would produce more than a 1°C rise in temperature. The second is that other things, such as adding soot and other aerosols to the atmosphere, add to or subtract from the effect of CO_2. All serious climate scientists agree on these two lines of reasoning. But they disagree on the size of the change that is predicted.

The Intergovernmental Panel on Climate Change (IPCC), which embodies the mainstream of climate science, reckons the answer is about 3°C, plus or minus a degree or so. In its most recent assessment (in 2007), it wrote that "the equilibrium climate sensitivity...is likely to be in the range 2°C to 4.5°C with a best estimate of about 3°C and is very unlikely to be less than 1.5°C. Values higher than 4.5°C cannot be excluded." The IPCC's next assessment is due in September. A draft version was recently leaked. It gave the same range of likely outcomes and added an upper limit of sensitivity of 6°C to 7°C.

A rise of around 3°C could be extremely damaging. The IPCC's earlier assessment said such a rise could mean that more areas would be affected by drought; that up to 30% of species could be at greater risk of extinction; that most corals would face significant biodiversity losses; and that there would be likely increases of intense tropical cyclones and much higher sea levels.

New Model Army

Other recent studies, though, paint a different picture. An unpublished report by the Research Council of Norway, a government-funded body, which was compiled by a team led by Terje Berntsen of the University of Oslo, uses a different method from the IPCC's. It concludes there is a 90% probability that doubling CO_2 emissions will increase temperatures by only 1.2-2.9°C, with the most likely figure being 1.9°C. The top of the study's range is well below the IPCC's upper estimates of likely sensitivity.

This study has not been peer-reviewed; it may be unreliable. But its projections are not unique. Work by Julia Hargreaves of the Research Institute for Global Change in Yokohama, which was published in 2012, suggests a 90% chance of the actual change being in the range of 0.5-4.0°C, with a mean of 2.3°C. This is based on the way the climate behaved about 20,000 years ago, at the peak of the last ice age, a period when carbon-dioxide concentrations leapt. Nic Lewis, an independent climate scientist, got an even lower range in a study accepted for publication: 1.0-3.0°C, with a mean of 1.6°C. His calculations reanalysed work cited by the IPCC and took account of more recent temperature data. In all these calculations, the chances of climate sensitivity above 4.5°C become vanishingly small.

If such estimates were right, they would require revisions to the science of climate change and, possibly, to public policies. If, as conventional wisdom has it, global temperatures could rise by 3°C or more in response to a doubling of emissions, then the correct response would be the one to which most of the world pays lip service: rein in the warming and the greenhouse gases causing it. This is called "mitigation", in the jargon. Moreover, if there were an outside possibility of something catastrophic, such as a 6°C rise, that could justify drastic interventions. This would be similar to taking out disaster insurance. It may seem an unnecessary expense when you are forking out for the premiums, but when you need it, you really need it. Many economists, including William Nordhaus of Yale University, have made this case.

If, however, temperatures are likely to rise by only 2°C in response to a doubling of carbon emissions (and if the likelihood of a 6°C increase is trivial), the calculation might change. Perhaps the world should seek to adjust to (rather than stop) the greenhouse-gas splurge. There is no point buying earthquake insurance if you do not live in an earthquake zone. In this case more adaptation rather than more mitigation might be the right policy at the margin. But that would be good advice only if these new estimates really were more reliable than the old ones. And different results come from different models.

One type of model—general-circulation models, or GCMs—use a bottom-up approach. These divide the Earth and its atmosphere into a grid which generates an enormous number of calculations in order to imitate the climate system and the multiple influences upon it. The advantage of such complex models is that they are extremely detailed. Their disadvantage is that they do not respond to new temperature readings. They simulate the way the climate works over the long run, without taking account of what current observations are. Their sensitivity is based upon how accurately they describe the processes and feedbacks in the climate system.

The other type—energy-balance models—are simpler. They are top-down, treating the Earth as a single unit or as two hemispheres, and representing the whole climate with a few equations reflecting things such as changes in greenhouse gases, volcanic aerosols and global temperatures. Such models do not try to describe the complexities of the climate. That is a drawback. But they have an advantage, too: unlike the GCMs, they explicitly use temperature data to estimate the sensitivity of the climate system, so they respond to actual climate observations.

The IPCC's estimates of climate sensitivity are based partly on GCMs. Because these reflect scientists' understanding of how the climate works, and that understanding has not changed much, the models have not changed either and do not reflect the recent hiatus in rising temperatures. In contrast, the Norwegian study was based on an energy-balance model. So were earlier influential ones by Reto Knutti of the Institute for Atmospheric and Climate Science in Zurich; by Piers Forster of the University of Leeds and Jonathan Gregory of the University of Reading; by Natalia ▸▸

Andronova and Michael Schlesinger, both of the University of Illinois; and by Magne Aldrin of the Norwegian Computing Centre (who is also a co-author of the new Norwegian study). All these found lower climate sensitivities. The paper by Drs Forster and Gregory found a central estimate of 1.6°C for equilibrium sensitivity, with a 95% likelihood of a 1.0-4.1°C range. That by Dr Aldrin and others found a 90% likelihood of a 1.2-3.5°C range.

It might seem obvious that energy-balance models are better: do they not fit what is actually happening? Yes, but that is not the whole story. Myles Allen of Oxford University points out that energy-balance models are better at representing simple and direct climate feedback mechanisms than indirect and dynamic ones. Most greenhouse gases are straightforward: they warm the climate. The direct impact of volcanoes is also straightforward: they cool it by reflecting sunlight back. But volcanoes also change circulation patterns in the atmosphere, which can then warm the climate indirectly, partially offsetting the direct cooling. Simple energy-balance models cannot capture this indirect feedback. So they may exaggerate volcanic cooling.

This means that if, for some reason, there were factors that temporarily muffled the impact of greenhouse-gas emissions on global temperatures, the simple energy-balance models might not pick them up. They will be too responsive to passing slowdowns. In short, the different sorts of climate model measure somewhat different things.

Clouds of uncertainty

This also means the case for saying the climate is less sensitive to CO_2 emissions than previously believed cannot rest on models alone. There must be other explanations—and, as it happens, there are: individual climatic influences and feedback loops that amplify (and sometimes moderate) climate change.

Begin with aerosols, such as those from sulphates. These stop the atmosphere from warming by reflecting sunlight. Some heat it, too. But on balance aerosols offset the warming impact of carbon dioxide and other greenhouse gases. Most climate models reckon that aerosols cool the atmosphere by about 0.3-0.5°C. If that underestimated aerosols' effects, perhaps it might explain the lack of recent warming.

Yet it does not. In fact, it may actually be an overestimate. Over the past few years, measurements of aerosols have improved enormously. Detailed data from satellites and balloons suggest their cooling effect is lower (and their warming greater, where that occurs). The leaked assessment from the IPCC (which is still subject to review and revision) suggested that aerosols' estimated radiative "forcing"—their warming or cooling effect—had changed from minus 1.2 watts per square metre of the Earth's surface in the 2007 assessment to minus 0.7W/m ^{2} now: ie, less cooling.

One of the commonest and most important aerosols is soot (also known as black carbon). This warms the atmosphere because it absorbs sunlight, as black things do. The most detailed study of soot was published in January and also found more net warming than had previously been thought. It reckoned black carbon had a direct warming effect of around 1.1W/m ^{2}. Though indirect effects offset some of this, the effect is still greater than an earlier estimate by the United Nations Environment Programme of 0.3-0.6W/m ^{2}.

All this makes the recent period of flat temperatures even more puzzling. If aerosols are not cooling the Earth as much as was thought, then global warming ought to be gathering pace. But it is not. Something must be reining it back. One candidate is lower climate sensitivity.

A related possibility is that general-circulation climate models may be overestimating the impact of clouds (which are themselves influenced by aerosols). In all such models, clouds amplify global warming, sometimes by a lot. But as the leaked IPCC assessment says, "the cloud feedback remains the most uncertain radiative feedback in climate models." It is even possible that some clouds may dampen, not amplify global warming—which may also help explain the hiatus in rising temperatures. If clouds have less of an effect, climate sensitivity would be lower.

So the explanation may lie in the air—but then again it may not. Perhaps it lies in the oceans. But here, too, facts get in the way. Over the past decade the long-term rise in surface seawater temperatures seems to have stalled (see chart 2), which suggests that the oceans are not absorbing as much heat from the atmosphere.

As with aerosols, this conclusion is based on better data from new measuring devices. But it applies only to the upper 700 metres of the sea. What is going on below that—particularly at depths of 2km or more—is obscure. A study in Geophysical Research Letters by Kevin Trenberth of America's National Centre for Atmospheric Research and others found that 30% of the ocean warming in the past decade has occurred in the deep ocean (below 700 metres). The study says a substantial amount of global warming is going into the oceans, and the deep oceans are heating up in an unprecedented way. If so, that would also help explain the temperature hiatus.

Double-A minus

Lastly, there is some evidence that the natural (ie, non-man-made) variability of temperatures may be somewhat greater than the IPCC has thought. A recent paper by Ka-Kit Tung and Jiansong Zhou in the Proceedings of the National Academy of Sciences links temperature changes from 1750 to natural changes (such as sea temperatures in the Atlantic Ocean) and suggests that "the anthropogenic global-warming trends might have been overestimated by a factor of two in the second half of the 20th century." It is possible, therefore, that both the rise in temperatures in the 1990s and the flattening in the 2000s have been caused in part by natural variability.

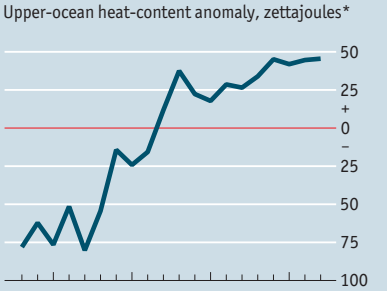
So what does all this amount to? The scientists are cautious about interpreting their findings. As Dr Knutti puts it, "the bottom line is that there are several lines of evidence, where the observed trends are pushing down, whereas the models are pushing up, so my personal view is that the overall assessment hasn't changed much."

But given the hiatus in warming and all the new evidence, a small reduction in estimates of climate sensitivity would seem to be justified: a downwards nudge on various best estimates from 3°C to 2.5°C, perhaps; a lower ceiling (around 4.5°C), certainly. If climate scientists were credit-rating agencies, climate sensitivity would be on negative watch. But it would not yet be downgraded.

Equilibrium climate sensitivity is a benchmark in climate science. But it is a very specific measure. It attempts to describe what would happen to the climate once all the feedback mechanisms have worked through; equilibrium in this sense takes centuries—too long for most policymakers. As Gerard Roe of the University of Washington argues, even if climate sensitivity were as high as the IPCC suggests, its effects would be minuscule ▸▸

The cool sea 2

Upper-ocean heat-content anomaly, zettajoules*



Source: Pacific Marine Environmental Laboratory

*10^{21} joules

under any plausible discount rate because it operates over such long periods. So it is one thing to ask how climate sensitivity might be changing; a different question is to ask what the policy consequences might be.

For that, a more useful measure is the transient climate response (TCR), the temperature you reach after doubling CO_2 gradually over 70 years. Unlike the equilibrium response, the transient one can be observed directly; there is much less controversy about it. Most estimates put the TCR at about 1.5°C, with a range of 1-2°C. Isaac Held of America's National Oceanic and Atmospheric Administration recently calculated his "personal best estimate" for the TCR: 1.4°C, reflecting the new estimates for aerosols and natural variability.

That sounds reassuring: the TCR is below estimates for equilibrium climate sensitivity. But the TCR captures only some of the warming that those 70 years of emissions would eventually generate because carbon dioxide stays in the atmosphere for much longer.

As a rule of thumb, global temperatures rise by about 1.5°C for each trillion tonnes of carbon put into the atmosphere. The world has pumped out half a trillion tonnes of carbon since 1750, and temperatures have risen by 0.8°C. At current rates, the next half-trillion tonnes will be emitted by 2045; the one after that before 2080.

Since CO_2 accumulates in the atmosphere, this could increase temperatures compared with pre-industrial levels by around 2°C even with a lower sensitivity and perhaps nearer to 4°C at the top end of the estimates. Despite all the work on sensitivity, no one really knows how the climate would react if temperatures rose by as much as 4°C. Hardly reassuring. ■

The future of the oceans

Acid test

Reprinted from The Economist, Nov 23rd 2013

The world's seas are becoming more acidic. How much that matters is not yet clear. But it might matter a lot

HUMANS, being a terrestrial species, are pleased to call their home "Earth". A more honest name might be "Sea", as more than seven-tenths of the planet's surface is covered with salt water. Moreover, this water houses algae, bacteria (known as cyanobacteria) and plants that generate about half the oxygen in the atmosphere. And it also provides seafood—at least 15% of the protein eaten by 60% of the planet's human population, an industry worth $218 billion a year. Its well-being is therefore of direct concern even to landlubbers.

That well-being, some fear, is under threat from the increasing amount of carbon dioxide in the atmosphere, a consequence of industrialisation. This concern is separate from anything caused by the role of CO_2 as a climate-changing greenhouse gas. It is a result of the fact that CO_2, when dissolved in water, creates an acid.

That matters, because many creatures which live in the ocean have shells or skeletons made of stuff that dissolves in acid. The more acidic the sea, the harder they have to work to keep their shells and skeletons intact. On the other hand, oceanic plants, cyanobacteria and algae, which use CO_2 for photosynthesis, might rather like a world where more of that gas is dissolved in the water they live in—a gain, rather than a loss, to ocean productivity.

Two reports attempting to summarise the world's rather patchy knowledge about what is going on have recently been published. Both are the products of meetings held last year (the wheels grind slowly in environmental bureaucracy). One, in Monterey, California, looked at the science. The other, in Monaco, looked at possible economic consequences. Together, the documents suggest this is an issue that needs to be taken seriously, though worryingly little is known about it.

Omega point

Regular, direct measures of the amount of CO_2 in the air date to the 1950s. Those of the oceans' acidity began only in the late 1980s (see chart). Since it started, that acidity has risen from pH 8.11 to pH 8.06 (on the pH scale, lower numbers mean more acid). This may not sound much, but pH is a logarithmic scale. A fall of one pH point is thus a tenfold rise in acidity, and this fall of 0.05 points in just over three decades is a rise in acidity of 12%.

Patchier data that go back further suggest there has been a 26% rise in oceanic acidity since the beginning of the industrial revolution, 250 years ago. Projections made by assuming that carbon-dioxide emissions will continue to increase in line with expected economic growth indicate this figure will be 170% by 2100.

Worrying about what the world may be like in nine decades might sound unnecessary, given more immediate problems, but another prediction is that once the seas have become more acidic, they will not quickly recover their alkalinity. Ocean life, in other words, will have to get used to it. So does this actually matter?

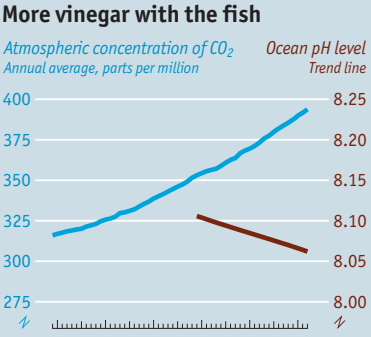
The variable people most worry about is called omega. This is a number that describes how threatening acidification is to seashells and skeletons. Lots of these are made of calcium carbonate, which comes in two crystalline forms: calcite and aragonite. Many critters, especially reef-forming corals and free-swimming molluscs (and most molluscs are free-swimming as larvae), prefer aragonite for their shells and skeletons. Unfortunately, this is more sensitive to acidity than calcite is.

An omega value for aragonite of one is the level of acidity where calcium carbonate dissolves out of the mineral as easily as it precipitates into it. In other words, the system is in equilibrium and shells made of aragonite will not tend to dissolve. Merely creeping above that value does not, however, get you out of the woods. Shell formation is an active process, and low omega values even above one make it hard. Corals, for example, require an omega value as high as three to grow their stony skeletons prolifically.

As the map above shows, that could be a problem by 2100. Low omega values are spreading from the poles (whose colder waters dissolve carbon dioxide more easily) towards the tropics. The Monterey report suggests that the rate of erosion of reefs could outpace reef building by the middle of the century, and that all reef formation will cease by the end of it.

Other species will suffer, too. A study published in Nature last year, for example, looked at the shells of planktonic snails called pteropods. In Antarctic waters, which already have an omega value of one, their ▸▸

More vinegar with the fish



Sources: NOAA; Scripps Institution of Oceanography

shells were weak and badly formed when compared with those of similar species found in warmer, more northerly waters. Earlier work on other molluscs has come to similar conclusions.

Not everything suffers from more dissolved CO_2, though. The Monterey report cites studies which support the idea that algae, cyanobacteria and sea grasses will indeed benefit. One investigation also suggests acidification may help cyanobacteria fix nitrogen and turn it into protein. Since a lack of accessible nitrogen keeps large areas of the ocean relatively sterile, this, too could be good for productivity.

The Monaco report attempts to identify fisheries that will be particularly affected by these changes. These include the Southern Ocean (one of the few areas not already heavily fished) and the productive fishery off the coast of Peru and northern Chile, where upwelling from the deep brings nutrients to the surface, but which is already quite acidic. The principal threat here, and to similar fisheries, such as that off the west coast of North America, is to planktonic larvae that fish eat. Oyster and clam beds around the world are also likely to be affected—again, the larvae of these animals are at risk. The report does not, though, investigate the possibility of increases in algal plankton raising the oceans' overall productivity.

At the back of everyone's mind (as in wider discussions of climate change) are events 56m years ago. At that time, the boundary between the Palaeocene and Eocene geological epochs, carbon-dioxide levels rose sharply, the climate suddenly warmed (by about 6°C) and the seas became a lot more acidic. Many marine species, notably coccolithophores (a group of shelled single-celled algae) and deep-dwelling foraminifera (a group of shelled protozoa), became extinct in mere centuries, and some students of the transition think the increased acidity was more to blame for this than the rise in temperature. Surface-dwelling foraminifera, however, thrived, and new coccolithophore species rapidly evolved to replace those that had died out.

On land, too, some groups of animals did well. Though the rise of the mammals is often dated from 66m years ago, when a mass extinction of the dinosaurs left the planet open for colonisation by other groups, it is actually the beginning of the Eocene, 10m years later, which marks the ascendancy of modern mammal groups.

Oceanic acidity levels appear now to be rising ten times as fast as they did at the end of the Palaeocene. Some Earth scientists think the planet is entering, as it did 56m years ago, a new epoch—the Anthropocene. Though the end of the Palaeocene was an extreme example, it is characteristic of such transitions for the pattern of life to change quickly. Which species will suffer and which will benefit in this particular transition remains to be seen. ■

The Arctic

The melting north

Reprinted from The Economist, Jun 16th 2012

The Arctic is warming twice as fast as the rest of the planet, says James Astill. The retreating ice offers access to precious minerals and new sea lanes—but also carries grave dangers

STANDING ON THE Greenland ice cap, it is obvious why restless modern man so reveres wild places. Everywhere you look, ice draws the eye, squeezed and chiselled by a unique coincidence of forces. Gormenghastian ice ridges, silver and lapis blue, ice mounds and other frozen contortions are minutely observable in the clear Arctic air. The great glaciers impose order on the icy sprawl, flowing down to a semi-frozen sea.

The ice cap is still, frozen in perturbation. There is not a breath of wind, no engine's sound, no bird's cry, no hubbub at all. Instead of noise, there is its absence. You feel it as a pressure behind the temples and, if you listen hard, as a phantom roar. For generations of frosty-whiskered European explorers, and still today, the ice sheet is synonymous with the power of nature.

The Arctic is one of the world's least explored and last wild places. Even the names of its seas and rivers are unfamiliar, though many are vast. Siberia's Yenisey and Lena each carries more water to the sea than the Mississippi or the Nile. Greenland, the world's biggest island, is six times the size of Germany. Yet it has a population of just 57,000, mostly Inuit scattered in tiny coastal settlements. In the whole of the Arctic—roughly defined as the Arctic Circle and a narrow margin to the south (see map)—there are barely 4m people, around half of whom live in a few cheerless post-Soviet cities such as Murmansk and Magadan. In most of the rest, including much of Siberia, northern Alaska, northern Canada, Greenland and northern Scandinavia, there is hardly anyone. Yet the region is anything but inviolate.

Fast forward

A heat map of the world, colour-coded for temperature change, shows the Arctic in sizzling maroon. Since 1951 it has warmed roughly twice as much as the global average. In that period the temperature in Greenland has gone up by 1.5°C, compared with around 0.7°C globally. This disparity is expected to continue. A 2°C increase in global temperatures—which appears inevitable as greenhouse-gas emissions soar—would mean Arctic warming of 3-6°C.

Almost all Arctic glaciers have receded. The area of Arctic land covered by snow in early summer has shrunk by almost a fifth since 1966. But it is the Arctic Ocean that is most changed. In the 1970s, 80s and 90s the minimum extent of polar pack ice fell by around 8% per decade. Then, in 2007, the sea ice crashed, melting to a summer minimum of 4.3m sq km (1.7m square miles), close to half the average for the 1960s and 24% below the previous minimum, set in 2005. This left the north-west passage, a sea lane through Canada's 36,000-island Arctic Archipelago, ice-free for the first time in memory. ▸▸

Breaching planetary boundaries

Scientists, scrambling to explain this, found that in 2007 every natural variation, including warm weather, clear skies and warm currents, had lined up to reinforce the seasonal melt. But last year there was no such remarkable coincidence: it was as normal as the Arctic gets these days. And the sea ice still shrank to almost the same extent.

There is no serious doubt about the basic cause of the warming. It is, in the Arctic as everywhere, the result of an increase in heat-trapping atmospheric gases, mainly carbon dioxide released when fossil fuels are burned. Because the atmosphere is shedding less solar heat, it is warming—a physical effect predicted back in 1896 by Svante Arrhenius, a Swedish scientist. But why is the Arctic warming faster than other places?

Consider, first, how very sensitive to temperature change the Arctic is because of where it is. In both hemispheres the climate system shifts heat from the steamy equator to the frozen pole. But in the north the exchange is much more efficient. This is partly because of the lofty mountain ranges of Europe, Asia and America that help mix warm and cold fronts, much as boulders churn water in a stream. Antarctica, surrounded by the vast southern seas, is subject to much less atmospheric mixing.

The land masses that encircle the Arctic also prevent the polar oceans revolving around it as they do around Antarctica. Instead they surge, north-south, between the Arctic land masses in a gigantic exchange of cold and warm water: the Pacific pours through the Bering Strait, between Siberia and Alaska, and the Atlantic through the Fram Strait, between Greenland and Norway's Svalbard archipelago.

That keeps the average annual temperature for the high Arctic (the northernmost fringes of land and the sea beyond) at a relatively sultry -15°C; much of the rest is close to melting-point for much of the year. Even modest warming can therefore have a dramatic effect on the region's ecosystems. The Antarctic is also warming, but with an average annual temperature of -57°C it will take more than a few hot summers for this to become obvious.

The albedo effect

The efficient north-south mixing of air may also play a part in the Arctic's amplified warming. The winds that rush northwards carry pollutants, including soot from European and Asian smokestacks, which has a powerful warming effect over snow. In recent decades there has also been a rise in levels of mercury, a by-product of burning coal, in the tissues of beluga whales, walruses and polar bears, all of which the Inuit eat. This is another reason why the Arctic is not virgin.

But the main reason for Arctic amplification is the warming effect of replacing light-coloured snow and ice with darker-coloured land or water. Because dark surfaces absorb more heat than light ones, this causes local warming, which melts more snow and ice, revealing more dark land or water, and so on. Known as the albedo effect, this turns out to be a more powerful positive feedback than most researchers had expected. Most climate models predicted that the Arctic Ocean could be ice-free in summer by the end of this century; an analysis published in 2009 in Geophysical Research Letters suggested it might happen as early as 2037. Some now think it will be sooner.

It is hard to exaggerate how dramatic this is. Perhaps not since the felling of America's vast forests in the 19th century, or possibly since the razing of China's and western Europe's great forests a thousand years before that, has the world seen such a spectacular environmental change. The consequences for Arctic ecosystems will be swingeing.

As their ancient ice buffers vanish, Arctic coastlines are eroding; parts of Alaska are receding at 14 metres (45 feet) a year. Niche habitats, such as meltwater pools on multi-year ice, are dwindling. Some highly specialised Arctic species will probably become extinct as their habitats shrink and southern interlopers rush in. Others will thrive. The early signs of this biological reshuffle are already evident. High-Arctic species, including the polar bear, are struggling. Species new to the region, such as mackerel and Atlantic cod, are coming up in Arctic trawler nets. Yet the shock waves of Arctic change will be felt much more widely.

Melting sea ice will not affect global sea levels, because floating ice displaces its own mass in seawater. But melting glaciers will, and the Arctic's are shedding ice at a great rate. Greenland's ice cap is losing an estimated 200 gigatonnes of ice a year, enough to supply a billion people with water. The Arctic's smaller ice caps and glaciers together are losing a similar amount. Before this became clear, the Intergovernmental Panel on Climate Change (IPCC) had predicted a sea-level rise of up to 59cm during this century. Given what is happening up north, many now think this too modest.

A wilder fear is that a deluge of Arctic meltwater could disrupt the mighty "overturning circulation" of the global oceans, the exchange of warm tropical and cold polar water. It has happened before, at least seven times in the past 60,000 years, and needs watching. But recent evidence suggests that such a calamity is not imminent. Another concern, that thawing Arctic permafrost could release vast quantities of carbon dioxide and methane, looms larger. That, too, has happened before, around 55m years ago, leading to a global temperature increase of 5°C in a few thousand years.

Such risks are hard to pin down, and possibly small. Many elements of the change in the Arctic, including the rates of snow melt and

glacier retreat, are still within the range of historical variations. Yet the fact that the change is man-made is unprecedented, which introduces huge uncertainty about how far and fast it will proceed. For those minded to ignore the risks, it is worth noting that even the more extreme predictions of Arctic warming have been outpaced by what has happened in reality.

Riches of the north

In the long run the unfrozen north could cause devastation. But, paradoxically, in the meantime no Arctic species will profit from it as much as the one causing it: humans. Disappearing sea ice may spell the end of the last Eskimo cultures, but hardly anyone lives in an igloo these days anyway. And the great melt is going to make a lot of people rich.

As the frozen tundra retreats northwards, large areas of the Arctic will become suitable for agriculture. An increasingly early Arctic spring could increase plant growth by up to 25%. That would allow Greenlanders to grow more than the paltry 100 tonnes of potatoes they manage now. And much more valuable materials will become increasingly accessible. The Arctic is already a big source of minerals, including zinc in Alaska, gold in Canada, iron in Sweden and nickel in Russia, and there is plenty more to mine.

The Arctic also has oil and gas, probably lots. Exploration licences are now being issued across the region, in the United States, Canada, Greenland, Norway and Russia. On April 18th ExxonMobil finalised the terms of a deal with Russia's Rosneft to invest up to $500 billion in developing offshore reserves, including in Russia's Arctic Kara sea. Oil companies do not like to talk about it, but this points to another positive feedback from the melt. Climate change caused by burning fossil fuels will allow more Arctic hydrocarbons to be extracted and burned.

These new Arctic industries will not emerge overnight. There is still plenty of sea ice to make the north exceptionally tough and expensive to work in; 24-hour-a-day winter darkness and Arctic cyclones make it tougher still. Most of the current exploration is unlikely to lead to hydrocarbon production for a decade at least. But in time it will happen. The prize is huge, and oil companies and Arctic governments are determined to claim it. Shortly before the ExxonMobil-Rosneft deal was announced, Vladimir Putin, Russia's president, announced plans to make it much more attractive for foreigners to invest in Russian offshore energy production. "Offshore fields, especially in the Arctic, are without any exaggeration our strategic reserve for the 21st century," he said.

For half the 20th century the Arctic, as the shortest route between Russia and America, was the likeliest theatre for a nuclear war, and some see potential for fresh conflict in its opening. Russia and Canada, the two biggest Arctic countries by area, have encouraged this fear: the Arctic stirs fierce nationalist sentiment in both. With a new regard to their northern areas, some of the eight Arctic countries are, in a modest way, remilitarising them. Norway shifted its military command centre to the Arctic town of Reitan in 2009. Russia is replacing and upgrading its six nuclear icebreakers, a piece of civilian infrastructure with implications for security too. Yet this special report will suggest that warnings about Arctic conflict are, like the climate, overcooked.

The Arctic is no terra nullius. Unlike Antarctica, which is governed by an international treaty, most of it is demarcated. Of half a dozen territorial disputes in the region, the biggest is probably between the United States and Canada, over the status of the north-west passage. Those two countries will not go to war. And the majority of Arctic countries are members of NATO.

Yet the melting Arctic will have geostrategic consequences beyond helping a bunch of resource-fattened countries to get fatter. An obvious one is the potentially disruptive effect of new trade routes. Sailing along the coast of Siberia by the north-east passage, or Northern Sea Route (NSR), as Russians and mariners call it, cuts the distance between western Europe and east Asia by roughly a third. The passage is now open for four or five months a year and is getting more traffic. In 2010 only four ships used the NSR; last year 34 did, in both directions, including tankers, refrigerated vessels carrying fish and even a cruise liner.

Asia's big exporters, China, Japan and South Korea, are already investing in ice-capable vessels, or planning to do so. For Russia, which has big plans to develop the sea lane with trans-shipment hubs and other infrastructure, this is a double boon. It will help it get Arctic resources to market faster and also, as the NSR becomes increasingly viable, diversify its hydrocarbon-addicted economy.

There are risks in this, of dispute if not war, which will require management. What is good for Russia may be bad for Egypt, which last year earned over $5 billion in revenues from the Suez Canal, an alternative east-west shipping route. So it is good that the regional club, the Arctic Council, is showing promise. Under Scandinavian direction for the past half-decade, it has elicited an impressive amount of Arctic co-operation, including on scientific research, mapping and resource development.

Yet how to reconcile the environmental risks of the melting Arctic with the economic opportunities it will present? The shrinkage of the sea ice is no less a result of human hands than the ploughing of the prairies. It might even turn out as lucrative. But the costs will also be huge. Unique ecosystems, and perhaps many species, will be lost in a tide of environmental change. The cause is global pollution, and the risks it carries are likewise global. The Arctic, no longer distant or inviolable, has emerged, almost overnight, as a powerful symbol of the age of man. ■

The rise of Genghis Khan

A horde of data

Reprinted from The Economist, Dec 8th 2012

The world's greatest land empire was probably encouraged by climate change

THE second half of the 20th century, Mongolia warmed by 2°C—an increase few, if any, other countries can match. Recent change has brought droughts and zuds (winter storms) which complicate the lives of the country's herders of sheep, cattle and goats as they adjust to a market economy after decades of communism. This year's meeting of the American Geophysical Union, in San Francisco, however, heard of an earlier change in the Mongolian climate that may have been responsible for complicating the lives of rather more than just a few herdsmen. For if Amy Hessl of West Virginia University and Neil Pederson of Columbia University are correct, it was an alteration in the climate that allowed Genghis Khan and his horde to conquer half of Eurasia.

The great Khan rose to power in 1206, the year he united Mongolia's tribes behind him, and died in 1227. Dr Hessl and Dr Pederson have tree-ring data which seem to show that from 1208 to 1231 Mongolia enjoyed a string of wetter-than-usual years which was longer than any other such period in the past millennium. Previous tree-ring studies show the same period was also unusually warm.

A clement climate lasting a generation would have provided richer grazing than normal. More fodder means more horses, and thus more of the wherewithal of empire—for if an army marches on its stomach, a horde surely gallops on its grazing. No one thinks that the Great Khan himself had nothing to do with it. But his strategic genius might have been for naught if the climate had provided him only with broken-down nags.

The next stage of the research, which also involves Nachin Baatarbileg of National University of Mongolia, will be to gather more samples. Tree-ring specialists like their trees old and stressed: old, because that gives insight into times for which no human records exist, and stressed because that exacerbates the climate's effect on growth. The trees the team are studying, which scrape a living on a lava field north of Karakorum, Genghis's capital, are both. The researchers also want to look at lake sediments. By counting spores from a fungus called Sporomiella, which grows in animal dung, they hope to find out whether there really was an animal-population boom at the time.

They are also broadening their team, by recruiting a historian and an ecosystem modeller. And they would like to extend their records back to the first millennium AD. The Khanate was not the only empire to rise from the grasses of Mongolia. The researchers want to know how climate influenced the Göktürk and Uyghur empires in the sixth to ninth centuries.

Historians and archaeologists have often argued that climate plays a role in the decline and fall of nations and empires, from the collapse of the eastern-Mediterranean bronze age, via the end of the Maya city-states of Central America, to the revolution that destroyed France's ancien regime. To link it to the rise of an empire is more unusual, and raises fascinating questions about the degree to which history can be enriched by the study of things such as the supply of available energy. It is even possible that a better understanding of Mongolia's past climate may help Genghis's descendants as they try to cope with the striking changes of the present. ■

Climate change and civilisation

Time and chance

Reprinted from The Economist, Dec 18th 2003

Natural climate change may have started civilisation. And the spread of farming may have caused as much global warming as industry is causing now

PEOPLE, like most animals, are naturally lazy. So the ascent of mankind is something of a mystery. Humans who make their livings hunting and gathering in the traditional way do not have to put much effort into it. Farmers who rely on rain to water their crops work significantly harder, and lead shorter and unhealthier lives. But the real back-breaking, health-destroying labour is that carried out by farmers who use irrigation. Yet it was the invention of irrigation, at first sight so detrimental to its practitioners, that actually produced a sufficient surplus to feed the priests, politicians, scholars, artists and so on whose activities are collectively thought of as "civilisation".

Given all the extra effort involved, why people first bothered to plant crops, and more particularly why they then went on to plant them near rivers running through deserts—with all the attendant canal-digging that required—is a puzzling question. But some light was shed on it at a recent meeting of the American Geophysical Union, in San Francisco. It may all, it seems, be down to climate change.

Necessity and invention

In the past 10,000 years, the world's climate has become temporarily colder and drier on several occasions. The first of these, known as the Younger Dryas, after a tundra-loving plant that thrived during it, occurred at the same time as the beginning of agriculture in northern Mesopotamia, in land now controlled by Turkey, Iraq and Syria. It is widely believed by students of the field that this was not a coincidence. The drying and cooling of the Younger Dryas adversely affected the food supply of hunter-gatherers. That would have created an incentive for agriculture to spread once some bright spark invented it.

Why farmers then moved on to irrigation is, however, far from clear. But Harvey Weiss, of Yale University, thinks he knows, and he outlined his ideas to the meeting.

Dr Weiss observes that the development of irrigation coincides with a second cool, dry period, some 8,200 years ago. His analysis of rainfall patterns in the area suggests that rainfall in agriculture's upper-Mesopotamian heartland would, at this time, have fallen below the level needed to sustain farming reliably. Farmers would thus have been forced out of the area in search of other opportunities.

Once again, an innovative spark was required. But it clearly occurred to some of these displaced farmers that the slow-moving waters of the lower Tigris and Euphrates, near sea level, could be diverted using canals and used to water crops. ▸▸

And the rest, as the cliché has it, is history.

Even irrigated civilisations are not, however, immune from climate change. One of Dr Weiss's former students, Sarah Parcak, of Cambridge University, presented data to the meeting on how a third period of cooling and drying, 4,200 years ago, destroyed the Old Kingdom of Egypt.

Ms Parcak re-analysed a number of satellite photographs to produce a comprehensive survey of "tells" in part of the Nile delta. A tell is a mound that marks the site of an ancient settlement (it is the result of debris from human activity in the settlement building up over the years). Her analysis located 44 previously unidentified tells, which she then dated from shards of pottery she picked up there. Adding her data to that from known and studied tells, she was able to tell, as it were, the story of the Old Kingdom's demise, and its connection with climate change.

Though Egyptian agriculture was (and still is) based on irrigation, the flow of the Nile is controlled ultimately by rainfall patterns at its headwaters. Ms Parcak found a precise correlation between settlement patterns in her study area and climate change. The population shrank drastically as the global climate cooled. Some 27 sites were occupied before this happened. That dropped to four after the change.

Of course, rain-fed agriculture is even more vulnerable to climate change than the irrigated variety, as Ms Parcak's Cambridge colleague Lauren Ristvet showed the conference with her study of northern Syria during the same period as the fall of Egypt's Old Kingdom. Like Ms Parcak, she identified sites from satellite photographs and then dated them by visiting them. She then correlated the data from these visits with estimates of local rainfall made by examining the composition of rocks from nearby caves. These suggested that rainfall had fallen by 20-30% in the global cooling 4,200 years ago. That may not sound disastrous, but it would have been enough to make farming in the area unviable.

The evidence on the ground suggests that this is exactly what happened. Agricultural villages disappeared, to be replaced by the temporary camps of pastoralists, whose herds grazed on wild plants which required less rainfall than farmed crops. It is not surprising, then, that this hitherto unobserved demographic change coincides with the collapse of the Akkadian empire, which controlled the area until 4,200 years ago.

Change and decay

So climate change helped to intensify agriculture, and thus start civilisation. But an equally intriguing idea put forward at the meeting is that the spread of agriculture caused climate change.

In this case, the presumed culprit is forest clearance. Most of the land cultivated by early farmers in the Middle East, Europe and southern China would have been forested. When the trees that grew there were cleared, the carbon they contained ended up in the atmosphere as carbon dioxide, a greenhouse gas. Moreover, one form of farming—the cultivation of rice in waterlogged fields—generates methane, another greenhouse gas, in large quantities. William Ruddiman, of the University of Virginia, explained to delegates his theory that, in combination, these two phenomena had warmed the atmosphere prior to the start of the industrial era by as much as all the greenhouse gases emitted since.

Dr Ruddiman's hypothesis is grounded on recent deviations from the regular climatic pattern of the past 400,000 years. This pattern is controlled by what are known as the Milankovitch cycles, which are in turn caused by periodic changes in the Earth's orbit and angle of tilt toward the sun. One effect of the Milankovitch cycles is to cause regular and predictable changes in the atmospheric concentrations of carbon dioxide and methane. These changes can be followed by studying ice cores taken in Antarctica.

According to Dr Ruddiman, the changes seen in the cores are as regular as clockwork until about 8,000 years ago. At that time carbon dioxide levels begin to rise at a point when they ought to start falling. About 5,000 years ago there is another upward deviation, this time in methane levels. The former, he contends, coincides with the beginning of extensive deforestation associated with the spread of agriculture into Europe and China. The latter coincides with the invention of "wet rice" farming. In combination, he calculates, these upward deviations make the atmosphere about 0.8°C warmer than it would otherwise be at this point in the Milankovitch cycles, independently of any greenhouse warming caused by industrialisation. That has been enough to keep parts of Canada that would otherwise be covered in glaciers, ice-free.

Of course, this is a difficult hypothesis to test. But Dr Ruddiman does have a test of sorts. Three times in the past 2,000 years, there have been periods of cooling (most recently, the "little ice age" of the 17th and 18th centuries). These, he notes, followed the three largest known periods of plague, when the human population shrank in various parts of the world. The first period was a series of plagues that racked the Roman empire from the third to the sixth centuries. The second was the Black Death and its aftermath. The third was the epidemic of smallpox and other diseases that reduced the population of the Americas from some 50m to about 5m in the centuries after Europeans arrived, and which coincided with the little ice age. In each case, a lot of previously farmed land turned back into forest, sucking carbon dioxide out of the atmosphere and cooling the climate. As environmentalists are wont to observe, mankind is part of nature. These observations show just how intimate the relationship is. ■

Global health

Lifting the burden

Reprinted from The Economist, Dec 15th 2012

People are living longer than ever before. But what they are dying of is changing in ways doctors have few answers to

"THIRD WORLD" is not a term much used today. Most developing countries, as they were once euphemistically known, really are now developing—and doing so fast. So it is not surprising their disease patterns are changing, too, just as happened in the rich world. Deaths from infectious disease are down. Rates of non-transmissible illness—often chronic and frequently the result of obesity are rising. The panjandrums of global health are struggling to keep up.

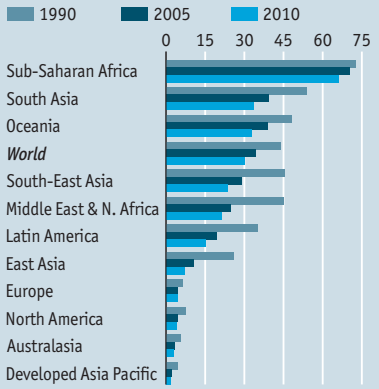
A series of reports in the Lancet, co-ordinated by Christopher Murray of the University of Washington, eloquently describes what is happening. Dr Murray and his colleagues looked at 291 sorts of disease and injury in almost every country in the world. They used death certificates, interviews, surveys, censuses, and records from hospitals and police stations to calculate life expectancy since 1970 and count the number of deaths by disease from 1990 to 2010. Most crucially, for 1990, 2005 and 2010 they tallied disability-adjusted life years, or DALYs (a measure of the years lost to ill-health, disability or early death).

The result should help the world's medical authorities direct their fire more effectively. For a decade, they have poured money into dealing with infections. Indeed, they have created new institutions, such as the inelegantly named Global Fund to Fight AIDS, Tuberculosis and Malaria, specifically dedicated to that task. This has worked well, and it certainly does not make sense to let up now. Nonetheless, the time may have come for a review of the world's approach to public health, for vaccination, antibiotics, insecticides and the like are useless against heart disease, diabetes and cancer. New ways of thinking about the problem are needed—both because chronic diseases require continuous treatment, and because many of the answers to the question "how can people in the 21st century have healthier lives?" are not strictly medical at all.

The most important message in Dr Murray's report is that the world is getting much healthier. The fundamental measurement of that—life expectancy at birth—has grown by leaps and bounds. Between 1970 and 2010 it rose, for women, from 61.2 years to 73.3. For men, who have always been more sickly, it went from 56.4 years to 67.5. In 1990 only 33% of those who died had passed their 70th birthdays. In 2010 that figure was 43%. In the intervening two decades 80 became the new 70. Nearly a quarter of 2010's deaths were of octogenarians. Some countries ▸▸

Goal keeping

Disability-adjusted life years attributable to Millennium Development Goals 4-6*, as % of total



*Reducing child mortality rates; improving maternal health; and combatting AIDS, malaria and other diseases

Source: "Global burden of diseases and injuries for 291 causes in 21 regions, 1990-2010", by Murray *et al*, The *Lancet*, 2012

made enormous gains. Bangladesh, Bhutan, Iran, the Maldives and Peru, for example, all saw life expectancy jump by more than 20 years.

Transmission breakdown

This rise in lifespan coincided with falls in the levels of many infectious diseases and also of malnutrition—and particularly of conditions that affect mothers and young children. These are problems that were picked by the United Nations as things to be attacked as part of that body's Millennium Development Goals. The hope was to reduce deaths caused by them, by 2015, by between a half and three-quarters of their 1990 levels. In 1990 they accounted for 47% of DALYs. By 2010 that was down to 35%.

The toll of deaths caused by diarrhoea, respiratory infections and measles all fell. HIV, which was not treatable at all until the mid-1990s, and not cheaply treatable until the middle of the last decade, was an exception, with the number of deaths rising by 390%. Even for HIV, however, the number of deaths peaked several years ago and is now falling. The only other serious outlier was malaria. The number of deaths this caused rose by 20% between 1990 and 2010—though that number, too, peaked in the middle of the last decade and is now falling. Contrary to received wisdom, however, Dr Murray and his team estimated that only six in ten of malaria deaths were of children under five. Previous estimates have usually been around nine in ten. And child mortality in general is dropping almost everywhere, often spectacularly. In Cuba, Portugal and Serbia it fell by more than 90% between 1970 and 2010.

The conventional targets of global-health campaigns, then, seem to be withering under the assault (see chart). But Dr Murray also confirmed what previous work suggested: that in most of the world now, the main afflictions are those you cannot catch from other people or mosquitoes. In 2010 such non-transmissible diseases, which had in 1990 caused 43% of DALYs, accounted for 54% of them. The share of DALYs caused by injuries in things like road accidents, or as a result of violence, was also up—from 10% to 11%. And although child mortality fell almost everywhere, there was a jump in the number of deaths of people aged 15-49, caused in part by the rise of HIV.

DALY bread

The biggest individual contribution to DALYs came from ischaemic heart disease (the sort involving blocked coronary arteries). In 1990 this was in fourth place. Strokes ranked third (up from fifth); low-back pain was sixth (it was previously 11th); injuries from road traffic came in tenth (previously 12th); depression was 11th (previously 15th); and diabetes was 14th (up from 21st). Collectively, heart conditions contributed 12% of DALYs and cancers nearly 8%. This would have put them first and second on the list had Dr Murray lumped them together rather than listed each type separately.

Partly, these changes are a consequence of the prolongation of life itself. Every year's rise in life expectancy brought nearly 42 weeks of healthy life, but it also brought around ten weeks of illness. Partly, though, it is because the underlying causes of disease have also shifted. In 1990 the top three predisposing factors were low body-weight in children (rendering them open to infection), indoor air pollution from cooking fuels (which encourages respiratory problems), and smoking (the bad effects of which are so well known as not to need enumerating). In 2010 high blood pressure (which encourages heart attacks and strokes) and alcohol consumption had replaced the first two, and only smoking remained on the list. Inactivity and poor diet—mainly eating too little fruit and too much salt—were also important, accounting for 10% of DALYs.

There was, however, wide variation from place to place. In America, Canada and western Europe smoking tobacco is the principal culprit for DALYs, whereas in eastern Europe it is overconsumption of alcohol. Diabetes, one of the dangerous consequences of being overweight, is a non-issue in most of sub-Saharan Africa but accounts for many DALYs in the Caribbean, Oceania (the small islands of the Pacific) and a region the report calls central Latin America (Venezuela, Colombia and countries north thereof as far as the Mexican border). The very top cause of DALYs in central Latin America, however, is not diabetes but violence. This was also near the top for Brazil and Paraguay, but ranked 65th in western Europe.

If you do fall ill, your prognosis also depends on where you live. The death rate from heart disease and strokes among young adults in Central Asia is five times western Europe's, while that from diabetes in Oceania is a staggering 26 times that in nearby Australia and New Zealand.

Facts like these present a conundrum for those who aspire to improve the world's health. Organisations such as the Bill & Melinda Gates Foundation and the Global Fund remain focused on infectious disease and perinatal care for good reason. Malaria, tuberculosis, HIV, and maternal and childhood death remain the top problems in the poorest countries, particularly those of sub-Saharan Africa. But in most of the rest they are no longer the prime worry. And what is now of concern—disease caused by overindulgence in food, alcohol and tobacco, and injuries caused by rapidly growing traffic and, in some places, a culture of casual violence—is not susceptible to prevention by medical means.

Road traffic, for example, requires action from planners, transport agencies and carmakers, not doctors or even officials from the health ministry. Taxing cigarettes and alcohol needs decisions from the finance ministry. Boosting exercise and the consumption of fruits and grains instead of salty foods and processed meats demands the most difficult change of all—in the behaviour of millions of individuals.

All this should inspire some serious head scratching. But, in a sense, humanity has been here before. Until 1854, supplying clean water to city dwellers and disposing of their sewage were seen as luxuries. It was only in that year that John Snow, a doctor working around the corner from The Economist's offices in London, showed that a tainted water supply could carry cholera. He did it by removing the handle from a particular public water pump, and thus ending a local epidemic.

Democracy and proper drains

Snow's discovery started the idea of public health, as opposed to individual medicine, and thus paved the way for the whole modern global-health apparatus. But it is often forgotten that it took not a doctor but a civil engineer, Joseph Bazalgette, to build the interceptor sewers along the banks of the Thames that ended cholera in London once and for all, and that Bazalgette himself relied on the reforming zeal of an increasingly democratic approach to politics that pervaded Victorian Britain.

As far as non-transmissible diseases are concerned, Snow's modern successors have already done their work. The physiological causes of these diseases are understood. What is needed is modern Bazalgettes who can devise ways to build health into the social and physical infrastructure, in the way the Victorians taught the world to build water pipes and sewers not merely as conveniences, but as lifesavers. ■

Free exchange

The weather report

Reprinted from The Economist, Jan 18th 2014

Economists are getting to grips with the impact of climate change

THE "polar vortex" that brought freezing weather to North America chipped roughly $3 billion off American output in a week. It was a reminder that extreme weather has economic

consequences even in the richest countries and that climate change—which may usher in even wilder fluctuations—is likely to have a big economic impact. A recent burst of studies look at how large it may be, adding useful detail to the initial efforts, such as the Stern review of 2010. The results suggest that climate change may be having an effect already; that the weather influences economies through a surprisingly wide range of channels; but that calculating the long-run effects of climate change is harder than estimating the short-run impact of weather.

The link between more heat and more poverty is robust. Tropical countries are poorer. In a review of the literature, Melissa Dell of Harvard University, Benjamin Jones of Northwestern University and Benjamin Olken of the Massachusetts Institute of Technology find that, for each 1°C rise in the average temperature of a country, its GDP per head is 8.5% lower. Another study of poor countries alone showed that being 1°C warmer in any given year reduces income per head by 1.4%. These findings would not have surprised Montesquieu, who in 1748 argued that hot climates were inimical to the material conditions of the good life.

But it does not follow that if global temperatures were to rise by 1°C because of climate change, then world output would be 8.5% lower than it would otherwise have been. Perhaps the correlation between heat and poverty might exist because of some third factor (for example, the presence of malaria). If it were possible to change that factor (ie, eradicate the disease), temperature might cease to matter. Recently, tropical regions from southern China to Rwanda have been among the world's most economically successful.

However, a correlation also exists between heat and growth, suggesting a longer-run effect. Despite some successes, tropical countries grew by 0.9 percentage points a year more slowly than the global average in 1965-90. In a sample of 28 Caribbean countries national output fell by 2.5% for each 1°C of warming. Again, this does not prove that high temperatures were to blame. But the correlation is strong enough to make it worth investigating whether the weather itself might be dragging down countries' growth rates directly. The new literature suggests several ways in which it might do that.

First, natural disasters still wreak a lot of damage. One study reckons cyclones pushed down the world's annual GDP growth by 1.3 points in 1970-2008. (Poor countries suffer disproportionately because they are more vulnerable to such disasters.) So if global warming were associated with more extreme weather, it would lower growth.

Next, higher temperatures and worse droughts tend to reduce farm yields. This hurts poor and middle-income countries most because agriculture has a bigger share in their GDP. To take one case, a decline in rainfall of one standard deviation cuts Brazilian farm incomes by 4%. But the agricultural effect of changing weather varies a lot. There seems to be a threshold of 29°-32°C below which rising temperatures can be beneficial; above it they are sharply harmful. With some crops, rising night-time temperatures do more damage than rising noontime ones. Farmers also adapt to higher temperatures by planting new crops or by emigrating to cities. So the impact of rising temperatures on farming is heterogeneous and hard to measure.

It is often assumed that the economic effects of climate change will be confined mainly to poor countries. That may be wrong. A study of time-use surveys and temperatures in the United States found that when temperatures reach 100°F (38°C), the labour supply in farming, forestry, construction and utilities falls by an hour a day, compared with what happens at 76-80°F. These are outdoor activities, which may explain why workers fail to show up. But a study of call centres also showed that each 1°C rise between 22°C and 29°C cut labour productivity by 1.8%. And in car factories in America, a week of outside temperatures above 90°F reduced output by 8%. Perhaps the heat disrupts the supply chain—or perhaps air conditioners fail to work properly.

Lastly, the weather influences basic conditions of life and hence factors of production. In America each additional day above 32°C raises the annual age-adjusted mortality rate by 0.1% relative to a temperate day (10-15°C). In India the rate increases by almost 0.8%. Heatwaves cause early deaths (especially of mothers and infants) and, by affecting the harvest, damage nutrition. This in turn has long-lasting effects on the economy.

Uncertain, with a chance of sub-optimal equilibrium

Almost all these correlations derive from weather data from the past five or ten years. But drawing conclusions about climate change—which takes place over hundreds of years—is perilous. Even more than with farming, the impact of climate change will be "non-linear": changes may be modest up to a point, then turn dramatic. Meanwhile, people can adapt in important ways to changing conditions. This makes simple extrapolation nonsense.

But the new literature is a start. It shows how information in models of climate impact—recently described as "completely made up"—can be improved. It shows the multiple channels that economists of the climate must heed. It suggests that climate change is not something that will affect only poor countries, or hit rich ones only in the distant future. And—who knows—it may one day show how public policy, now so ineffective, might stem the emissions that are causing the mess in the first place.

Sources
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"Quantifying the influence of climate on human conflict", by Solomon Hsiang, Marshall Burke and Edward Miguel
"Envirodevonomics" by Michael Greenstone and Kelsey Jack. MIT Working Paper series ■

Livestock diseases

On the zoonose

Reprinted from The Economist, Jan 18th 2014

Where demand for meat grows, so does the risk of an outbreak

ZOONOSES—diseases transmitted from animals to people—seem to be becoming more serious. It is hard to be sure, since the huge fall in worldwide mortality since 1950 makes comparisons hard. But according to Delia Grace of the International Livestock Research Institute in Nairobi, zoonoses cause a fifth of premature deaths in poor countries. The 13 most severe, including brucellosis and leptospirosis (bacterial infections transmitted by body fluids), as well as bovine tuberculosis and rabies, lead to 2.4 billion cases of illness and 2.2m deaths a year, more than HIV/AIDS and diarrhoea.

Intensive farming is one cause. Animals crowded in unsanitary conditions are more likely to get diseases and transmit them to humans. The doubling of the global meat trade in 20 years has been concentrated in just nine countries. That cuts the chance of transmission, but means that a disease that crosses into people is likely to do more harm.

Intensive agriculture, however, is not the full explanation. Zoonotic diseases are least deadly in Europe and America, despite their factory farms, because of better disease control and public concern about health—both of humans and animals. These have led to modest changes: the European Union banned battery cages for chickens in 2012.

The poorest countries, which have traditional pastoralist systems, rarely see novel zoonotic diseases such as severe acute respiratory syndrome (SARS) or highly pathogenic avian influenza. But that does not mean their animals are healthier. Many diseases are endemic and epidemics are frequent: a quarter of livestock in developing countries have, or have had, leptospirosis.

The biggest threat of an outbreak is now in big emerging markets with growing middle classes, such as Brazil and China, where demand for meat is soaring and farmers are switching to intensive livestock production. That puts them at a dangerous point. They have the factory farms that can spread disease, but so far lack the improved standards of food safety and animal husbandry that would mitigate the risks. ■

Governing the high seas

In deep water

Reprinted from The Economist, Feb 22nd 2014

Humans are damaging the high seas. Now the oceans are doing harm back

ABOUT 3 billion people live within 100 miles (160km) of the sea, a number that could double in the next decade as humans flock to coastal cities like gulls. The oceans produce $3 trillion of goods and services each year and untold value for the Earth's ecology. Life could not exist without these vast water reserves—and, if anything, they are becoming even more important to humans than before.

Mining is about to begin under the seabed in the high seas—the regions outside the exclusive economic zones administered by coastal and island nations, which stretch 200 nautical miles (370km) offshore. Nineteen exploratory licences have been issued. New summer shipping lanes are opening across the Arctic Ocean. The genetic resources of marine life promise a pharmaceutical bonanza: the number of patents has been rising at 12% a year. One study found that genetic material from the seas is a hundred times more likely to have anti-cancer properties than that from terrestrial life.

But these developments are minor compared with vaster forces reshaping the Earth, both on land and at sea. It has long been clear that people are damaging the oceans—witness the melting of the Arctic ice in summer, the spread of oxygen-starved dead zones and the death of coral reefs. Now, the consequences of that damage are starting to be felt onshore.

Thailand provides a vivid example. In the 1990s it cleared coastal mangrove swamps to set up shrimp farms. Ocean storm surges in 2011, no longer cushioned by the mangroves, rushed in to flood the country's industrial heartland, causing billions of dollars of damage.

More serious is the global mismanagement of fish stocks. About 3 billion people get a fifth of their protein from fish, making it a more important protein source than beef. But a vicious cycle has developed as fish stocks decline and fishermen race to grab what they can of the remainder. According to the Food and Agriculture Organisation (FAO), a third of fish stocks in the oceans are over-exploited; some estimates say the proportion is more than half (see chart). One study suggested that stocks of big predatory species—such as tuna, swordfish and marlin—may have fallen by as much as 90% since the 1950s. People could be eating much better, were fishing stocks properly managed.

The forests are often called the lungs of the Earth, but the description better fits the oceans. They produce half the world's supply of oxygen, mostly through photosynthesis by aquatic algae and other organisms. But according to a forthcoming report by the Intergovernmental Panel on Climate Change (IPCC; the group of scientists who advise governments on global warming), concentrations of chlorophyll (which helps makes oxygen) have fallen by 9-12% in 1998-2010 in the North Pacific, Indian and North Atlantic Oceans.

Climate change may be the reason. At the moment, the oceans are moderating the impact of global warming—though that may not last. Warm water rises, so an increase in sea temperatures tends to separate cold and warm water into more distinct layers, with shallower mixed layers in between. That seems to lower the quantity of nutrients available for aquatic algae, and to lead to decreased chlorophyll concentrations. Changes in the oceans, therefore, may mean less oxygen will be produced. This cannot be good news, though scientists are still debating the likely consequences. The world is not about to suffocate. But the result could be lower oxygen concentrations in the oceans and changes to the climate because the counterpart of less oxygen is more carbon—adding to the build-up of greenhouse gases. In short, the decades of damage wreaked on the oceans are now damaging the terrestrial environment.

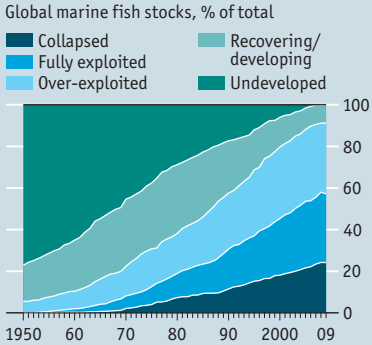
A tragedy foretold

The oceans exemplify the "tragedy of the commons"—the depletion of commonly held property by individual users, who harm their own long-term interests as a result. For decades scientists warned that the European Union's fishing quotas were too high, and for decades fishing lobbyists persuaded politicians to ignore them. Now what everyone knew would happen has happened: three-quarters of the fish stocks in European waters are over-exploited and some are close to collapse.

The salient feature of such a tragedy is that the full cost of damaging the system is not borne by those doing the damage. This is most obvious in fishing, but goes further. Invasive species of many kinds are moved around the world by human activity—and do an estimated $100 billion of damage to oceans each year. Farmers dump excess fertiliser into rivers, which finds its way to the sea; there cyanobacteria (blue-green algae) feed on the nutrients, proliferate madly and ▸▸

Net losses

Global marine fish stocks, % of total



Source: "What catch data can tell us about the status of global fisheries", by Rainer Froese *et al*, *Marine Biology*, March 2012

reduce oxygen levels, asphyxiating all sea creatures. In 2008, there were over 400 "dead zones" in the oceans. Polluters pump out carbon dioxide, which dissolves in seawater, producing carbonic acid. That in turn has increased ocean acidity by over a quarter since the start of the Industrial Revolution. In 2012, scientists found pteropods (a kind of sea snail) in the Southern Ocean with partially dissolved shells.

It is sometimes possible to preserve commons by assigning private property rights over them, thus giving users a bigger stake in their long-term health. That is being tried in coastal and island nations' exclusive economic zones. But it does not apply on the high seas. Under international law, fishing there is open to all and minerals count as "the common heritage of mankind". Here, a mishmash of international rules and institutions determines the condition of the watery commons.

The high seas are not ungoverned. Almost every country has ratified the UN Convention on the Law of the Sea (UNCLOS), which, in the words of Tommy Koh, president of UNCLOS in the 1980s, is "a constitution for the oceans". It sets rules for everything from military activities and territorial disputes (like those in the South China Sea) to shipping, deep-sea mining and fishing. Although it came into force only in 1994, it embodies centuries-old customary laws, including the freedom of the seas, which says the high seas are open to all. UNCLOS took decades to negotiate and is sacrosanct. Even America, which refuses to sign it, abides by its provisions.

But UNCLOS has significant faults. It is weak on conservation and the environment, since most of it was negotiated in the 1970s when these topics were barely considered. It has no powers to enforce or punish. America's refusal to sign makes the problem worse: although it behaves in accordance with UNCLOS, it is reluctant to push others to do likewise.

Alphabet bouillabaisse

Specialised bodies have been set up to oversee a few parts of the treaty, such as the International Seabed Authority, which regulates mining beneath the high seas. But for the most part UNCLOS relies on member countries and existing organisations for monitoring and enforcement. The result is a baffling tangle of overlapping authorities (see diagram) that is described by the Global Ocean Commission, a new high-level lobby group, as a "co-ordinated catastrophe".

Individually, some of the institutions work well enough. The International Maritime Organisation, which regulates global shipping, keeps a register of merchant and passenger vessels, which must carry identification numbers. The result is a reasonably law-abiding global industry. It is also responsible for one of the rare success stories of recent decades, the standards applying to routine and accidental discharges of pollution from ships. But even it is flawed. The Institute for Advanced Sustainability Studies, a German think-tank, rates it as the least transparent international organisation. And it is dominated by insiders: contributions, and therefore influence, are weighted by tonnage.

Other institutions look good on paper but are untested. This is the case with the seabed authority, which has drawn up a global regime for deep-sea mining that is more up-to-date than most national mining codes. For once, therefore, countries have settled the rules before an activity gets under way, rather than trying to catch up when the damage starts, as happened with fishing.

The problem here is political rather than regulatory: how should mining revenues be distributed? Deep-sea minerals are supposed to be "the common heritage of mankind". Does that mean everyone is entitled to a part? And how to share it out?

The biggest failure, though, is in the regulation of fishing. Overfishing does more damage to the oceans than all other human activities there put together. In theory, high-seas fishing is overseen by an array of regional bodies. Some cover individual species, such as the International Commission for the Conservation of Atlantic Tunas (ICCAT, also known as the International Conspiracy to Catch All Tuna). Others cover fishing in a particular area, such as the north-east Atlantic or the South Pacific Oceans. They decide what sort of fishing gear may be used, set limits on the quantity of fish that can be caught and how many ships are allowed in an area, and so on.

Here, too, there have been successes. Stocks of north-east Arctic cod are now the highest of any cod species and the highest they have been since 1945—even though the permitted catch is also at record levels. This proves it is possible to have healthy stocks and a healthy fishing industry. But it is a bilateral, not an international, achievement: only Norway and Russia capture these fish and they jointly follow scientists' advice about how much to take.

There has also been some progress in controlling the sort of fishing gear that does the most damage. In 1991 the UN banned drift nets longer than 2.5km (these are nets that hang down from the surface; some were 50km long). A series of national and regional restrictions in the 2000s placed limits on "bottom trawling" (hoovering up everything on the seabed)—which most people at the time thought unachievable.

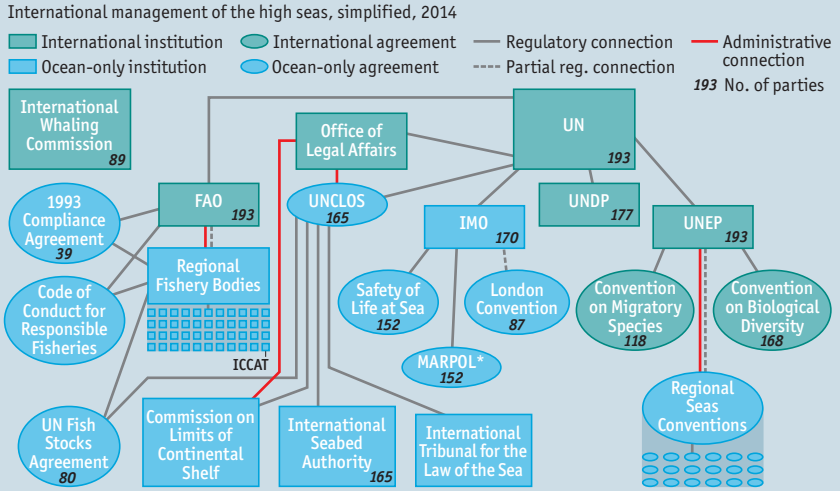
But the overall record is disastrous. Two-thirds of fish stocks on the high seas are over-exploited—twice as much as in parts of oceans under national jurisdiction. Illegal and unreported fishing is worth $10 billion-24 billion a year—about a quarter of the total catch. According to the World Bank, the mismanagement of fisheries costs $50 billion or more a year, meaning that the fishing industry would reap at least that much in efficiency gains if it were properly managed.

Most regional fishery bodies have too little money to combat illegal fishermen. They do not know how many vessels are in their waters because there is no global register of fishing boats. Their rules only bind their members; outsiders can break them with impunity. An expert review of ICCAT, the tuna commission, ordered by the organisation itself concluded that it was "an international disgrace". A survey by the FAO found that over half the countries reporting on surveillance and enforcement on the high seas said they could not control vessels sailing under their flags. Even if they wanted to, then, it is not clear that regional fishery bodies or individual countries could make much difference.

But it is far from clear that many really ▸▸

Trouble at sea

International management of the high seas, simplified, 2014



Sources: Global Oceans Commission; *The Economist*

*International Convention for the Prevention of Pollution from Ships

want to. Almost all are dominated by fishing interests. The exceptions are the organisation for Antarctica, where scientific researchers are influential, and the International Whaling Commission, which admitted environmentalists early on. Not by coincidence, these are the two that have taken conservation most seriously.

Empty promises

Countries could do more to stop vessels suspected of illegal fishing from docking in their harbours—but they don't. The FAO's attempt to set up a voluntary register of high-seas fishing boats has been becalmed for years. The UN has a fish-stocks agreement that imposes stricter demands than regional fishery bodies. It requires signatories to impose tough sanctions on ships that break the rules. But only 80 countries have ratified it, compared with the 165 parties to UNCLOS. One study found that 28 nations, which together account for 40% of the world's catch, are failing to meet most of the requirements of an FAO code of conduct which they have signed up to.

It is not merely that particular institutions are weak. The system itself is dysfunctional. There are organisations for fishing, mining and shipping, but none for the oceans as a whole. Regional seas organisations, whose main responsibility is to cut pollution, generally do not cover the same areas as regional fishery bodies, and the two rarely work well together. (In the north-east Atlantic, the one case where the boundaries coincide, they have done a lot.) Dozens of organisations play some role in the oceans (including 16 in the UN alone) but the outfit that is supposed to co-ordinate them, called UN-Oceans, is an ad-hoc body without oversight authority. There are no proper arrangements for monitoring, assessing or reporting on how the various organisations are doing—and no one to tell them if they are failing.

Pressure for change is finally building up. According to David Miliband, a former British foreign secretary who is now co-chairman of the Global Ocean Commission, the current mess is a "terrible betrayal" of current and future generations. "We need a new approach to the economics and governance of the high seas," he says.

That could take different forms. Environmentalists want a moratorium on overfished stocks, which on the high seas would mean most of them. They also want regional bodies to demand impact assessments before issuing fishing licences. The UN Development Programme says rich countries should switch some of the staggering $35 billion a year they spend subsidising fishing on the high seas (through things like cheap fuel and vessel-buy-back programmes) to creating marine reserves—protected areas like national parks.

Others focus on institutional reform. The European Union and 77 developing countries want an "implementing agreement" to strengthen the environmental and conservation provisions of UNCLOS. They had hoped to start what will doubtless be lengthy negotiations at a UN conference in Rio de Janeiro in 2012. But opposition from Russia and America forced a postponement; talks are now supposed to start by August 2015.

Still others say that efforts should be concentrated on improving the regional bodies, by giving them more money, greater enforcement powers and mandates that include the overall health of their bits of the ocean. The German Advisory Council on Global Change, a think-tank set up by the government, argues for an entirely new UN body, a World Oceans Organisation, which it hopes would increase awareness of ocean mismanagement among governments, and simplify and streamline the current organisational tangle.

According to Elinor Ostrom, who won the Nobel prize for economics in 2009, to avoid a tragedy of the commons requires giving everyone entitled to use them a say in running them; setting clear boundaries to keep out those who are not entitled; appointing monitors who are trusted by users; and having straightforward mechanisms to resolve conflicts. At the moment, the governance of the high seas meets none of those criteria.

Changes to high-seas management would still do nothing for two of the worst problems, both caused on land: acidification and pollution. But they are the best and perhaps only hope of improving the condition of half of the Earth's surface. ■

A dwindling catch

Governing the oceans

The tragedy of the high seas

Reprinted from The Economist, Feb 22nd 2014

New management is needed for the planet's most important common resource

IN 1968 an American ecologist, Garrett Hardin, published an article entitled "The Tragedy of the Commons". He argued that when a resource is held jointly, it is in individuals' self-interest to deplete it, so people will tend to undermine their collective long-term interest by over-exploiting rather than protecting that asset. Such a tragedy is now unfolding, causing serious damage to a resource that covers almost half the surface of the Earth.

The high seas—the bit of the oceans that lies beyond coastal states' 200-mile exclusive economic zones—are a commons. Fishing there is open to all. Countries have declared minerals on the seabed "the common heritage of mankind". The high seas are of great economic importance to everyone—fish is a more important source of protein than beef—and getting more so. The number of patents using DNA from sea-creatures is rocketing, and one study suggests that marine life is a hundred times more likely to contain material useful for anti-cancer drugs than is terrestrial life.

Yet the state of the high seas is deteriorating. Arctic ice now melts away in summer. Dead zones are spreading. Two-thirds of the fish stocks in the high seas are over-exploited, even more than in the parts of the oceans under national control. And strange things are happening at a microbiological level. The oceans produce half the planet's supply of oxygen, mostly thanks to chlorophyll in aquatic algae. Concentrations of that chlorophyll are falling. That does not mean life will suffocate. But it could further damage the climate, since less oxygen means more carbon dioxide.

For tragedies of the commons to be averted, rules and institutions are needed to balance the short-term interests of individuals against the long-term interests of all users. That is why the dysfunctional policies and institutions governing the high seas need radical reform.

Net loss

The first target should be fishing subsidies. Fishermen, who often occupy an important place in a country's self-image, have succeeded in persuading governments to spend other people's money subsidising an industry that loses billions and does huge environmental damage. Rich nations hand the people who are depleting the high seas $35 billion a year in cheap fuel, insurance and so on. The sum is over a third of the value of the catch. That should stop. ▸▸

Second, there should be a global register of fishing vessels. These have long been exempt from an international scheme that requires passenger and cargo ships to carry a unique ID number. Last December maritime nations lifted the exemption—a good first step. But it is still up to individual countries to require fishing boats flying their flag to sign up to the ID scheme. Governments should make it mandatory, creating a global record of vessels to help crack down on illegal high-seas fishing. Somalis are not the only pirates out there.

Third, there should be more marine reserves. An eighth of the Earth's land mass enjoys a measure of legal protection (such as national-park status). Less than 1% of the high seas does. Over the past few years countries have started to set up protected marine areas in their own economic zones. Bodies that regulate fishing in the high seas should copy the idea, giving some space for fish stocks and the environment to recover.

But reforming specific policies will not be enough. Countries also need to improve the system of governance. There is a basic law of the sea signed by most nations (though not America, to its discredit). But it contains no mechanisms to enforce its provisions. Instead, dozens of bodies have sprung up to regulate particular activities, such as shipping, fishing and mining, or specific parts of the oceans. The mandates overlap and conflict. Non-members break the rules with impunity. And no one looks after the oceans as a whole.

A World Oceans Organisation should be set up within the UN. After all, if the UN cannot promote collective self-interest over the individual interests of its members, what is it good for? Such an organisation would have the job of streamlining the impenetrable institutional tangle. But it took 30 years to negotiate the law of the sea. A global oceans body would probably take longer—and the oceans need help now.

So in the meantime the law of the sea should be beefed up. It is a fine achievement, without which the oceans would be in an even worse state. But it was negotiated in the 1970s before the rise of environmental concerns, so contains little on biodiversity. And the regional fishing bodies, currently dominated by fishing interests, should be opened up to scientists and charities. As it is, the sharks are in charge of the fish farm.

This would not solve all the problems of the oceans. Two of the biggest—acidification and pollution—emanate from the land. Much of the damage is done within the 200-mile limit. But institutional reform for the high seas could cut overfishing and, crucially, change attitudes. The high seas are so vast and distant that people behave as though they cannot be protected or do not need protection. Neither is true. Humanity has harmed the high seas, but it can reverse that damage. Unless it does so, there will be trouble brewing beneath the waves. ■

Agricultural biodiversity

Banking against Doomsday

Reprinted from The Economist, Mar 10th 2012

Gene banks represent an overdue push to preserve crop biodiversity. It also needs conserving on farms

WITH a heavy clunk, the steel outer doors of the Svalbard Global Seed Vault closed on February 28th, shutting out a howling Arctic gale and entombing a tonne of new arrivals: 25,000 seed samples from America, Colombia, Costa Rica, Tajikistan, Armenia and Syria. For Cary Fowler, the vault's American architect, the Syrian chickpeas and fava beans were especially welcome.

Opened in 2008, the Svalbard vault is a backup for the world's 1,750 seed banks, storehouses of agricultural biodiversity. To illustrate the need for it, the Philippines' national seed bank was destroyed by fire in January, six years after it was damaged by flooding. Those of Afghanistan and Iraq were destroyed in recent wars. Should the conflict in Syria reach that country's richest store, in Aleppo, the damage would now be less. Some 110,000 Syrian seed samples are now in the Svalbard vault, out of around 750,000 samples in all. "When I see this," says Mr Fowler, looking lovingly at his latest consignment, "I just think, 'thank goodness, they're safe.'"

The Svalbard vault is protected by two airlocks, at the end of a tunnel sunk 160 metres into the permafrost of Norway's Arctic archipelago, outside the village of Longyearbyen, one of the world's most northerly habitations. It is maintained at a constant temperature of -18°C. This is serious disaster preparedness: if its electricity were cut, Mr Fowler reckons the vault would take two centuries to warm to freezing point. He also enthusiastically points to its concave tunnel-head, designed to deflect the force of a missile strike. Such precautions have spawned the facility's nickname: the Doomsday Vault.

Mr Fowler, who manages it on behalf of Norway's government, an association of Nordic gene banks and an international body, the Global Crop Diversity Trust, reckons the vault contains samples of around two-thirds of the world's stored crop biodiversity. To augment this, he will also soon embark on a project, funded with $50m from Norway, to collect the seeds of many crops' wild ancestors.

A seedy business

Most seed banks were created in the 1970s and 1980s, towards the end of a global surge in crop yields, wrought largely through the adoption of hybridised seed varieties, known as the Green Revolution. The idea was born of a realisation that a vast amount of agricultural biodiversity was being lost, as farmers abandoned old seeds, often locally developed over centuries, for the new hybrids.

The extent of the loss, which continues today, is poorly documented. The extinction of non-human species is generally better studied than the loss of the genetic material that sustains humanity. Yet, largely on the basis of named crop varieties that are no longer extant, the UN's Food and Agriculture Organisation estimates that 75% of crop biodiversity has been lost from the world's fields. India is reckoned to have had over 100,000 varieties of rice a century ago; it now has only a few thousand. America once ▸▸

had around 5,000 apple varieties, and now has a few hundred. Such measures probably underestimate the scale of the losses, because a single traditional seed variety often contains a lot of genetic diversity.

It is hard to quantify how much this matters; but the long-term risks are potentially huge. Agricultural biodiversity is the best hedge against future blights, including pests, diseases and climate change. That is why plant breeders, from poor smallholders to the world's biggest biotech firms, masters of the genetically modified organism (GMO), continuously update their genetic stock, often from obscure sources.

"If we ignore genetic diversity while we develop GMO products, we risk a disease or pest emerging that will wipe those types out," says John Soper, head of crop genetics research at Pioneer Hi-Bred, the seed division of DuPont, a chemicals giant. He says the firm has drawn genetic material from its stock of wild American sunflower seeds three or four times in the past decade, in a bid to make its commercial varieties resistant to broomrape, a parasitic blight of southern Europe. It also has plans to cope with climate change, having recently opened a research outfit in chilly western Canada. It is trying to develop local varieties of maize (corn) and soyabean, which are not grown there commercially, but may be as the temperature climbs.

Yet biotech firms cannot be relied upon to look after crop biodiversity. Their gene banks are too small and too concentrated on a handful of commercial crops. Their urge to make profits is not necessarily aligned with the wider cause of feeding mankind. Hence a recent push to boost national gene banks, of which the Svalbard vault is a product.

It is a heartening display of international co-operation. In the vault's frozen sanctum, North Korean seeds, in neat brown wooden boxes, sit alongside stocks from South Korea—and from Congo, Bangladesh and Peru. In many such developing countries, gene banks are impoverished and badly managed, which is another threat to their stocks. Pondering one of the risks, Mr Fowler warns "a millennium of agricultural activity can disappear one night in a bowl of porridge."

Let them wither on the vine

Yet seed banks are not the only answer to saving crop biodiversity: it also needs conserving in fields. This is because seed banks rarely store varieties of crop that do not produce seeds, including cassava, bananas and many other fruits and berries. They also rarely record local knowledge of their deposits, which can be almost as important as the seeds themselves. Unlike seed banks, moreover, nature is anything but ossified: it is gloriously adaptable. Over the past 15 years in West Africa, for example, populations of traditional sorghum varieties have been observed shortening their growth cycle by two weeks in response to a curtailed rainy season. The best way to harness this adaptability is simply to let nature get on with it.

Farmers' eagerness to jettison their wily old landraces is understandable. Improved varieties of seed are estimated to have boosted yields by 21-43%, independently of fertilisers and other inputs. To conserve crop biodiversity amid the inevitable rush for hybrids, seed banks have an important role. But another solution—as to many climate-related problems—is to make drastic improvements in land-use planning, and then encourage strategically placed farmers to dedicate a small area to traditional crops. Ways of doing this include developing niche markets for their endearingly old-school vegetables and grains or even, as in Nepal, with the national equivalent of a harvest festival. Its government regularly dishes out prizes to those farmers with the most biodiverse land.

Such measures are less glamorous and more troublesome than depositing seeds in an Arctic bunker kindly paid for by Norwegian taxpayers. That is why they are too rarely taken, which is a great shame. If the world did a better job of tending crop biodiversity in its fields, the feared Doomsday after which the vault is nicknamed would be even less likely to come. ■

Brazil's conversion

Trees of knowledge

Reprinted from The Economist, Sep 14th 2013

How Brazil is using education, technology and politics to save its rainforest

MAURO LUCIO IS living the dream. Having started work as a cowboy at 16, he is now 48 and raises cattle on 50 square kilometres of Paragominas municipality in Pará state. The animals on his ranch are healthy, the grass thick and the fences solid. Along the avenues on his estate, wooden posts name the many different varieties of trees he has planted between the fields. His wife serves delicious food while his three daughters play happily on the verandah of the handsome wooden ranch house.

The only thing that is not ideal about Mr Lucio's estate is its history. Until around ten years ago it was part of the rainforest. The biggest trees, up to 100 feet tall, were sold for timber, the rest burnt. In this way Brazil has lost around 19% of its Amazonian forest. And Brazil makes up around 63% of the Amazon region.

Half of the world's plant and animal species are believed to live in rainforest, so destroying it is a sure way of wiping out large swathes of biodiversity. Species are put at risk not just when forest is burned but also when clearing cuts up the remaining forest into smaller and smaller fragments. A study conducted over three decades by Thomas Lovejoy, an American scientist, shows that creatures die when the forest becomes more and more fragmented, partly because it dries up and partly because some species are deprived of the range they need to survive.

Until recently it would have been normal practice in the area for Mr Lucio to occupy his ranch for a few years, then, when productivity dropped—as it tends to on the rather thin rainforest soil—burn down some more and move on. But Mr Lucio has no plans to do that, nor, if they are to be believed, do any of the other ranchers in Paragominas. Burning down the rainforest, in addition to having been outlawed, has also become socially unacceptable. Mr Lucio is focusing on raising his income not by colonising more land but by increasing his farm's productivity.

Space-age solution

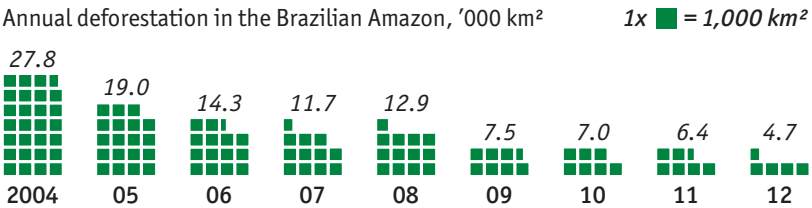
When Luiz Inácio Lula da Silva became president in 2003, his government, under pressure from public opinion and foreigners, turned against deforestation. From 2003 his environment minister, Marina Silva, started giving greater protection to land in the Amazon and beefed up the federal environmental police, the Ibama. Centres of illegal logging, such as Paragominas, were put on a blacklist.

Ms Silva was greatly helped by a combination ▸▸

Logging off

Can't see the deforestation for the trees

Annual deforestation in the Brazilian Amazon, '000 km²



Source: Imazon

of remote sensing and a Brazilian NGO, Imazon. Brazil's space agency published figures on deforestation, but only on an annual basis, nearly a year in retrospect and without a map, so nobody knew exactly where the trees were coming down. Beto Verissimo, who founded Imazon to use science for the benefit of the rainforest, realised that NASA's Modis satellite collected data that could be published monthly and would also show were the damage was being done. In 2007 Imazon started processing NASA's data and publishing them within a few weeks of being collected.

Partly because of rising prosperity and partly because of international attention, Brazilians were getting more interested in the fate of the Amazon. Newspapers started putting Imazon's data on their front pages. State governors had to respond to them on national news programmes. Month after month, Mato Grosso and Pará were found to have the highest rates of deforestation.

In 2008 the government ratcheted up the pressure, publishing a list of the 36 municipalities with the worst records. Seventeen, including Paragominas, were in Pará state. Being blacklisted did not just bring public humiliation to the citizens of Paragominas, it also hit their wallets. Businesses in municipalities on the list were not eligible for cheap credit from state-owned banks.

Adnan Demachki, Paragominas's mayor, saw that Greenpeace's boycott of soya produced from Amazonian estates was hitting the soya farmers of Mato Grosso and realised that something similar was about to happen to the beef producers of Pará. He went round making speeches to local groups to persuade them that deforestation had to stop.

The federal public prosecutor in Pará, Daniel Avelino, followed the supply chain back from the supermarkets through the beef companies to the ranchers to find out which animals had been produced on illegally deforested land, and threatened the supermarkets with prosecution. "They reacted fast," says Mr Avelino. "It was about their brand, their visibility to the public." Brazil's supermarket association—which includes Walmart and Carrefour—said its members would stop buying beef from recently deforested land.

This made Mr Avelino exceedingly unpopular. He received death threats and still travels with an armed guard. But he was not alone in applying economic pressure. The International Finance Corporation, the private-finance arm of the World Bank, withdrew a loan it had promised to Bertin, a big beef producer, to expand its facilities in the Amazon.

Mr Demachki persuaded local trade associations to commit to stopping deforestation. In April 2008 he fined three farmers who were still at it. In October 2008 he was re-elected with 88% of the vote. But not everybody liked what was happening, and things came to a head that November night when the environmental-police station went up in flames.

Since then deforestation in the municipality has pretty much stopped and Paragominas has become a model town. It has a Green Lake, a Green Stadium and a Green Park in the centre of town. A museum built from illegally felled, confiscated wood shows, with admirable neutrality, how Paragominas performed its U-turn on deforestation. Since the 1960s two-fifths of the municipality has been cleared of forest. The plan is for about 15% of the cleared area to go back to forest, and half of the rest to be left to cattle-ranching and half to arable farming.

In 2011 Simão Jatene, Pará's newly elected governor, decided to replicate Paragominas's achievements around the state. Central to this effort is the Cadastro Ambiental Rural (CAR), the rural environmental registry. Uncertainty about land tenure is a big administrative stumbling block in Brazil. Some farmers do not have title to the land they farm; some give money to people in whose name land is registered, known as laranjas—oranges—so that the real owners are not held to account for deforesting it. "If you have a speed trap but the cars have no numbers, that's useless," says Mr Avelino. Rather than try to delve into the history of every piece of land, the state governments in Mato Grosso and Pará are trying to get farmers to apply for a CAR certificate so the government knows who is using the land and how much forest it is supposed to have. Banks now require loan applicants to produce a CAR; beef companies will buy only from farms with a CAR. In Pará the number of properties with a CAR has gone up from 600 in 2009 to 80,000 now.

Deforestation in Pará has more or less come to a halt. In the Brazilian Amazon as a whole, it has fallen from 28,000 sq km in 2004 to under 5,000 sq km last year (see chart). Although small farmers continue to clear land in areas where the authority of the state is weak, the big beef and soya companies that used to do it themselves or buy produce from those that did no longer want anything to do with it.

Brazil's success—so far—demonstrates how many elements have to come together to make such policies work. You need clear direction not just at the top but all the way through government. Ms Silva's determination was crucial, but if her views had not had the support of Mr Jatene, Mr Avelino and Mr Demachki, she would not have got far. You need administrators with enough imagination to find novel solutions: the CAR was a way around an apparently insuperable land-tenure problem. You need a functioning police force: if the Ibama had not been effective, the politicians' and prosecutor's intentions would have been impossible to implement. You need businessmen whose conscience or share price induces them to change their supply chains. You need NGOs, such as Greenpeace and Imazon, to badger business and government to do things differently. You need independent media to pick the story up and run with it. And, crucially, you need a public that cares: if voters and consumers were indifferent, none of this would happen.

Help from foreigners, especially Americans, has been important too—though, given Brazilian sensitivity to interference by gringos, some of them keep quiet about it. Imazon's Mr Verissimo was inspired by Chris Uhl, an American field ecologist working in Pará in the 1980s who is now a professor at Penn State. Imazon was founded with grants from USAID and the MacArthur Foundation. The Ford Foundation funded a sustainable forestry project in Paragominas. NASA provides the satellite data that Imazon publishes. Google has built a platform to allow Imazon to process the data more quickly and cheaply, and Imazon is now training people from other rainforest countries to use it. Mr Lovejoy's forest-fragments project has been running for 30 years, bringing in a stream of foreign researchers, employing Brazilian scientists and pointing out the consequences of slicing the forest up into little bits. Greenpeace's international

campaign against Brazilian soya, beef and leather put pressure on global businesses such as Walmart, Carrefour and Nike, and that put pressure on Brazilian companies. So although globalisation exacerbated deforestation by boosting demand for Brazilian produce, it is also part of the solution.

Keep at it

But the problem is still not solved once and for all. Deforestation rates may rebound. If locals can prosper without chopping trees down, there is a good chance that the rest of the forest will survive. If they can't, it won't.

Migration should help. These days it flows away from the Amazon rather than towards it. Brazil is urbanising fast, and the attractions of scrubbing a living from raising cows on deforested land are diminishing.

Still, there are plenty of people left in the countryside, and stopping deforestation means destroying jobs. In Paragominas only 14 of the city's 240 sawmills are still working, and the charcoal industry has closed down. Yet after a brief downturn, the city is doing pretty well. One reason is in evidence in the town hall, where about 50 ranch hands in cowboy hats and baseball caps listen raptly to a presentation on human-bovine interaction. "Control by understanding animal behaviour," says a slide, "not by aggression." "Suffering in the cow represents loss of quality in the meat," says another.

The course is part of a Green Ranching Project, run by Mr Lucio in his capacity as head of the local branch of the farmers' union. Better animal welfare is a by-product: the initiative's main aim is to increase output so that farmers can prosper without deforesting more land. Mr Lucio's farm shows it can be done. Average production for the region, he says, is 90kg of beef per hectare per year; his average is 500kg and his profit margin 40%. Other than happy cows, his secrets are dietary supplements in their feed, fertiliser for the grass, allowing pastures to regenerate after 48 days of grazing and planting copses in his fields to shelter his cattle from the heat.

The combination of better education and chemicals means that farmers like Mr Lucio can prosper without destroying the forest. This is progress from which all species can benefit. ■

China and the environment

The East is grey

Reprinted from The Economist, Aug 10th 2013

China is the world's worst polluter but largest investor in green energy. Its rise will have as big an impact on the environment as on the world economy or politics

ALL industrial nations one day hit an environmental turning-point, an event that dramatises to the population the ecological consequences of growth. In America that event occurred in 1969 when the Cuyahoga river in Ohio, thick with pollutants and bereft of fish, caught fire. America's Environmental Protection Agency was founded the next year. Strict environmental laws passed by Japan in the 1970s followed the realisation that poisonous mercury spilled from a plastics factory was claiming thousands of lives around the bay of Minamata.

The fetid smog that settled on Beijing in January 2013 could join the ranks of these game-changing environmental disruptions. For several weeks the air was worse than in an airport smoking lounge. A swathe of warm air in the atmosphere settled over the Chinese capital like a duvet and trapped beneath it pollution from the region's 200 coal-fired power plants and 5m cars. The concentration of particles with a diameter of 2.5 microns or less, hit 900 parts per million—40 times the level the World Health Organisation deems safe. You could smell, taste and choke on it.

Public concern exploded. China's hyperactive microblogs logged 2.5m posts on "smog" in January alone. The dean of a business school said thousands of Chinese and expatriate businessmen were packing their bags because of the pollution. Beijing is one of China's richest cities. Before the 2008 Olympic games it had relocated its smelliest industries to surrounding provinces. If anywhere should be cleaning itself up, it is the capital. Yet even Communist bigwigs, opening their curtains each morning near the Forbidden City, could not avoid the toxic fog.

Journey to the West

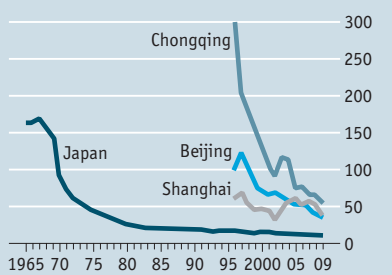
The "airpocalypse" injected a new urgency into local debate about the environment—and produced a green-policy frenzy a few months later. In three weeks from the middle of June, the government unveiled a series of reforms to restrict air pollution. It started the country's first carbon market, made prosecuting environmental crimes easier and made local officials more accountable for air-quality problems in their areas. It also said China—meaning companies as well as government—would spend $275 billion over the next five years cleaning up the air. Even by Chinese standards that is serious money, equivalent to Hong Kong's GDP or twice the size of the annual defence budget.

Is this China's turning-point? Many environmentalists, both in the country and outside, fear it is too little, too late. A study released by America's National Academy of Sciences in July found that air pollution in the north of China reduces life expectancy by five-and-a-half years. The rivers are filthy, the soil contaminated. The government has long known this and attempted to clean things

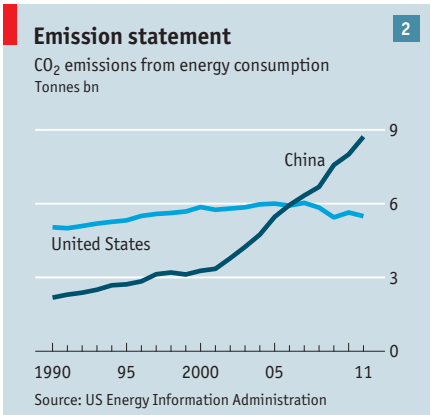
Bad air days 1

Average annual sulphur-dioxide concentrations

Micrograms per cubic metre



Source: World Bank



up. Yet still the smog comes.

And there is something else in the air, less immediately damaging but with a far bigger global impact. China's greenhouse-gas emissions were about 10% of the world's total in 1990. Now they are nearer 30%. Since 2000 China alone has accounted for two-thirds of the global growth in carbon-dioxide emissions. This will be very hard to reverse. While America and Europe are cutting their emissions by 60m tonnes a year combined, China is increasing its own by over 500m tonnes. This makes it a unique global threat.

Nonsense, say Chinese officials. China is not responsible for the build-up of greenhouse gases. The West is. There are environmental problems, true, but China is simply following a pattern set by Britain, America and Japan: "grow first, clean up later". China grew unusually fast but it is now cleaning up unusually fast, too. Its efforts to rein in pollution are undervalued; its investments in wind and solar power put others to shame; its carbon emissions will peak sooner than people expect. China will one day do for zero-carbon energy what it has already done for consumer electronics—put it within reach of everyone. It will not be a threat to the planet but the model for how to clean it up.

China is broadly right about one thing: its environmental problems do have historical parallels. With the exception of Chongqing, the largest municipality, most Chinese cities are no more polluted than Japan's were in 1960 (see chart 1). Excluding spikes like that in Beijing this year, air quality is improving at about the same rate as Japan's did in the 1970s.

Other environmental indicators are worse, however, and it is not clear whether they are improving as fast. A 2006 survey found that almost 10% of farmland was contaminated with heavy metals, such as cadmium. Whether a recent nationwide soil survey showed an improvement is hard to say, as the Ministry of Environmental Protection promptly declared the findings a state secret. The discovery of rice tainted with cadmium in Guangdong this year triggered panic buying of Thai rice.

China's wildlife is under particular threat. The China Species Red List, an official document, classified almost 40% of the country's mammals as "threatened" in 2004. An unusually wide range of habitats—China is exceptionally diverse in this respect—is being degraded by industrial development.

The Water Margin

The worst problem is water. Pictures of China often show green and watery landscapes. But most of northern China is as dry as straw. "Severe water stress" is usually defined as access to less than 1,000 cubic metres of water per person per year. For China the figure is just 450 cubic metres. The national average is bad enough but it hides an even more alarming regional disparity. Four-fifths of the water is in the south—mainly in the Yangzi river basin (see map). Half the people and two-thirds of the country's farmland are in the parched north—mainly in the Yellow river basin. In Beijing there is just 100 cubic metres per person per year. The water table there has fallen by 300 metres in two decades. Wen Jiabao, a former prime minister, was barely exaggerating when he said water shortages "threaten the very survival of the Chinese nation".

Such shortages have been a problem for centuries but they are being exacerbated now by pollution. The Yellow River Conservancy Commission, a government body, surveyed the "mother river" of China and found that for a third of its length the water was too polluted for use in agriculture. The housing ministry's chief engineer for water safety says only half the water sources in urban areas are fit to drink.

Severe though China's problems with water, soil and air are, they are not different in kind from those of other nations in the past. As Pan Jiahua of the Chinese Academy of Social Sciences (CASS) puts it, "We're following the US, Japan and UK and because of inertia we don't have the capacity to stop quickly."

China's impact on the climate, though, is unique. Its economy is not only large but also resource-hungry. It accounts for 16% of world output but consumes between 40% and 50% of the world's coal, copper, steel, nickel, aluminium and zinc. It also imports half the planet's tropical logs and raises half its pigs.

The country's energy use is similarly gargantuan. This is in part because, under Mao, the use of energy was recklessly profligate. China's consumption of energy per unit of GDP tripled in 1950-78—an unprecedented "achievement". In the early 1990s, at the start of its period of greatest growth, China was still using 800 tonnes of coal equivalent (tce, a unit of energy) to produce $1m of output, far more than other developing countries. Energy efficiency has since improved; China used 390tce per $1m in 2009. But that was still more than the global average of 300tce and far more than Germany, which used only 173tce.

Despite a huge hydroelectric programme, most of this energy comes from burning coal on a vast scale. China currently burns about half the world's supplies. In 2006 it surpassed America in carbon-dioxide emissions from energy (see chart 2). By 2014 or 2015 it will emit twice America's total. Between 1990 and 2050 its cumulative emissions from energy will amount to some 500 billion tonnes—roughly the same as those of the whole world from the beginning of the industrial revolution to 1970. And the total is what matters. The climate reacts to the stock of carbon, not to annual rises.

These emissions are adding to a build-up of carbon already pushed to unprecedented heights by earlier industrialisations. When Britain began the process in the 18th century, the atmosphere's carbon-dioxide level was 280 parts per million (ppm). When Japan was industrialising fastest in the late 1950s, it had risen a bit, to 315ppm. This year the level hit 400ppm. Avoiding dangerous climate change is widely taken to mean keeping below 450ppm, although there are significant uncertainties surrounding this figure. At current rates that threshold will be reached in 2037. China is likely to be the largest emitter between now and then.

About a quarter of China's carbon emissions is produced making goods for export. If the carbon embodied in those goods were marked against the ledgers of the importing countries China would look a little less damaging, the rich world a lot less virtuous. But even allowing for that, China is not playing catch-up any more. It is doing more damage to the stability of the global climate than any other country.

Strange Tales from a Chinese Studio

China will suffer as much as anywhere. Already its deserts are spreading, farmland is drying out and crop yields are plateauing. Climate change may make matters worse. It has 80m people living at sea level who are vulnerable to rising oceans and higher storm surges. And as heavy manufacturing and mining move from coastal areas to poorer western provinces like Xinjiang and Tibet, the shift may increase environmental damage. These areas have particularly fragile ecosystems and degradation could quickly become irreversible.

Some of those problems may not become ▸▸

Don't drink the water; don't even touch the water

acute for a while. But the nation's immediate environmental woes are already challenging the basic contract between rulers and people: rising living standards in exchange for acquiescence in the Communist Party's monopoly of power.

The costs of environmental and natural-resource degradation, according to the World Bank, are the equivalent of 9% of GDP, an enormous amount which is dragging down the long-term growth rate. The biggest downdrafts include health damage from air pollution and the degradation of soil nutrients. And since the party takes credit for the benefits of growth, it gets blamed for the costs of pollution. As Ma Jun, China's best-known environmental activist, puts it, "Everyone knows the link between the environment and their own health." None of the challenges facing the new generation of leaders is bigger than those posed by the environment.

China is already doing a lot to meet that challenge, on paper at least. Even before the Beijing smog settled, the government had issued 20 significant anti-pollution laws and tens of thousands of decrees. It established a Ministry for Environmental Protection in 2008 and at the last Communist Party conference in 2012, added the environment to the four "platforms"—basic beliefs that define what the party stands for. In China, that sort of signal matters.

But the new leaders worry at least as much about faltering short-term growth as about environmental degradation. The prime minister, Li Keqiang, reflected these conflicting demands in his inaugural address in March, when he said: "It is no good having prosperity and wealth while the environment deteriorates,"—but then said it was just as bad to have "poverty and backwardness in the midst of clear waters and verdant mountains."

In the West it is often said that one of China's chief advantages in dealing with climate change is that its leaders can impose tough policies that democratic systems shy away from. Mr Wen once said the government would use "an iron hand" to make the country more energy-efficient. But in environmental matters the government does not have an iron hand.

If local officials—mayors and provincial or county party secretaries—do not like a policy, they can quietly ignore it. As an official in Guangdong once said about pollution controls, "We don't think these decisions apply to us." The bosses of large state-owned companies often wield as much power as the ministers who supervise them. Occult systems of patronage matter more than apparent hierarchies. In the Chinese system, the centre proposes; provinces and counties dispose.

The system is changing to reflect environmental concerns. Guizhou is one of the poorest parts of China. It also sits atop large reserves of coal. A few years ago it would have happily mined them. But in formulating a new development plan to catch up with the rest of the country, it is relying more on imported natural gas from Myanmar—partly to fulfil the various anti-pollution diktats from the centre.

But change is slow. One of the ways the centre can directly influence local officials is through the criteria used when judging who gets promoted. Until now the economy was the most important factor. Environmental considerations have been added over the years, albeit with fuzzy measurements. President Xi Jinping is trying to make greenery more important by saying officials will be held responsible for environmental problems in an area, even after they have been promoted out of it.

So far, though, tinkering with the promotion system has not worked. According to a study for America's National Bureau of Economic Research, mayors who spent money on environmental projects (pollution-treatment plants and the like) in 2000-09 had a lower chance of promotion than those investing in infrastructure that boosted the economy, such as roads. Growth remains the main consideration locally and it is not yet clear that the centre can change this.

Dream of the Green Chamber

In the West public opinion put the environment on the map, forcing governments and firms to clean up. But it is not clear this will happen soon in China. True, the public is worried. Figures from CASS suggest a quarter of demonstrations are about the environment. They cannot be put down as easily as peasant protests: they are often middle-class, urban affairs which might one day become a nationwide movement. If China's leaders want a reminder of why this prospect might matter, they need only look at the former Soviet Union. In all but one of the European countries that split away from the USSR, the political parties that formed the first governments began life as environmental movements.

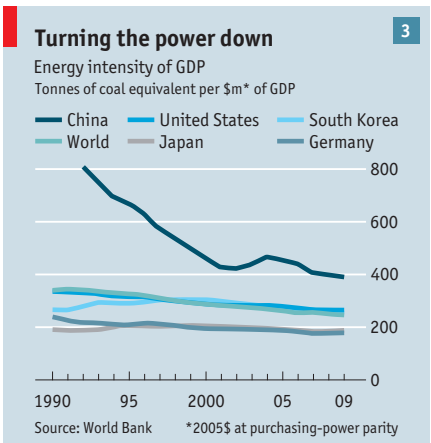
But the government can downplay public pressure for the moment because the environment remains, it seems, a second-tier concern. According to Xinhua, China's news agency, an opinion poll in February 2012 found that worries about food safety came third, after income inequality and soaring house prices. In March a poll in China Youth Daily, a party newspaper, also put food safety third, after corruption and income distribution; and in November 2012 China Daily said 52.6% of respondents set environmental degradation fourth on their list of anxieties, after the wealth gap, corruption and the power of vested interests.

Moreover, most environmental protests are local rather than national. Demonstrators complain about this city's air or that city's water, but not about China's overall situation. Activists like Mr Ma concede that as a mass movement environmentalism is in its infancy.

The wider implication is that far from being good at solving environmental problems, the Chinese political system is no better than anyone else's. The top is ambivalent, the middle sceptical and the grassroots weak and divided.

Given all that, the remarkable thing is not what China has failed to do but what it has achieved, especially in reining in carbon dioxide. Its carbon emissions are growing at half the rate of GDP, a bit better than the global average. China has also boosted investment in renewable energy far more than any other country. It has the world's most ambitious plans for building new nuclear power stations.

To combine economic growth and environmental improvement, China has concentrated on reducing carbon intensity—emissions per unit of GDP (see chart 3). This



fell by about 20% in the past five years and the government is aiming to cut it by 40-45% by 2020, compared with 2005. Most of the improvement is coming from a scheme to bully 1,000 state-owned enterprises (SOEs) into using energy more efficiently—arguably the single most important climate policy in the world.

The enterprises sign a contract with the central government agreeing to meet efficiency targets, abide by new building codes and install environmental-control equipment. This helped Chinese cement-makers (who produce as much of the stuff as the rest of the world put together) reduce the energy needed to make a tonne of cement by 30% in the ten years to 2009. The scheme has now been expanded to 10,000 SOEs, covering the majority of polluters.

China is also generating energy more efficiently. According to the World Bank, better operations and the closure of clapped-out plants helped to push the average thermal efficiency of its coal-fired power stations from 31% in 2000 to 37% in 2010; America's remained flat, at 33%.

The other big energy change is China's vast renewables programme. The government aims to get 20% of its energy from such sources by 2020, the same target as in richer Europe. The largest slice will come from hydropower, which accounted for around 15% of total energy in 2012 (with nuclear power at 2%). But the big rise comes from wind and solar: the government will roughly double investment in these two in 2011-16, compared with 2006-10. Chinese investment in renewables puts others to shame. It amounted to $67 billion in 2012, says REN21, a network of policymakers, more than three times what Germany spent. The aim is to have 100 gigawatts of wind capacity and 35 gigawatts of solar capacity by 2015.

Even by the standards of renewables, though, much of this is inefficient. China and America have almost the same windpower capacity but America gets 40% more energy from it. Chinese wind farms—classic creations of central planning—are often not plugged in or create power surges so big that the electricity grid cannot cope and they have to be unplugged again.

Dirty coal will remain China's most important fuel for the foreseeable future (hopes of a shale-gas revolution may be constrained by water shortages). Coal is cheaper and, as Nat Bullard of Bloomberg New Energy Finance, a firm of market analysts, points out, it provides "baseload power"—continuous energy unaffected by a lack of sun or wind. Its cost advantages will shrink, though. China is the world's lowest-cost producer of solar panels. Mr Bullard says solar power should become competitive without subsidies by 2020.

As well as these supply-side measures, the government is also trying to reduce emissions by capping them and introducing a carbon price. The idea is unpopular in some quarters and is being introduced in stages—slipped in, as it were.

Along with reducing the targets it sets for energy intensity, China is setting up a pilot carbon-trading scheme in seven cities and provinces. Next, it plans to cap the amount of energy consumed, probably at 4 billion tce in 2015. That would require a sharp reduction in energy growth. The third stage is to turn the energy cap into a national emissions target. This is supposed to happen in 2016-20. The aim is to pave the way, in 2021-25, for provincial carbon budgets and a national carbon-trading system.

There is a lot of scepticism about whether this will happen as planned. But the basic aim—to rein in the rise of carbon emissions more quickly—may be met. A few years ago Chinese politicians said such emissions would go on rising at least until 2050. Now mainstream Chinese opinion says the peak will come in 2030-40. Academics at the Energy Research Institute and CASS reckon it could come earlier—in 2025-30. Compared with what seemed likely a few years ago, that would be a big achievement.

But compared with what China needs to do, it would not be enough. As a rough guide the world needs to restrict emissions to a little over 700 billion tonnes of carbon dioxide between now and 2050, if global temperatures are not to increase by more than 2°C above pre-industrial levels. The Stockholm Environment Institute calculates that, if China continues on its current path, it would emit almost two-thirds of that budget—roughly 450 billion tonnes— on its own. If it tries to live within its share of the global budget (which would be 220 billion tonnes, assuming countries' shares of total emissions stay at current levels), then its emissions would have to fall to zero within ten years of a 2025 peak. This is inconceivable.

Call to Arms

The world appears destined to break that 700 billion tonne budget quite dramatically. How much of the overrun will be due to China? Over the next 20 years, it will build the equivalent of an America's worth of new houses; the switch from rural to urban life roughly doubles energy use and carbon emissions per person. If China reaches the current living standards of industrial countries, the number of cars on its roads will rise tenfold.

Against that, and more importantly, the structure of the economy will change. Services account for 43% of GDP, a much lower proportion than in other middle-income countries. China can reasonably expect to increase the share of services, which are far less polluting, over the next 20 years.

Meanwhile, China could do even more to help itself. Its pricing of basic resources is skewed. Water and fertilisers in particular are too cheap, discouraging saving of its most precious resource. The country relies too much on command-and-control mechanisms and is hampered by bureaucratic complexity.

Yet China also has advantages in addressing its—and the world's—environmental problems. Its leaders understand the challenge of climate change better than their predecessors and perhaps their international peers, too. They are good at taking action on high-priority issues. Because the country is a late developer, it should be able to learn from the mistakes of others—and not build energy-guzzling cities. China has a huge domestic market, cheap capital and sunny, windy deserts: the ideal environment to build a zero-carbon energy system. It is the silver lining of a very dark cloud. If China cannot do it, no one can. ■

Obituary

Elinor Ostrom

Reprinted from The Economist, Jun 30th 2012

Elinor Ostrom, defender of the commons, died on June 12th, aged 78

IT SEEMED to Elinor Ostrom that the world contained a large body of common sense. People, left to themselves, would sort out rational ways of surviving and getting along. Although the world's arable land, forests, fresh water and fisheries were all finite, it was possible to share them without depleting them and to care for them without fighting. While others wrote gloomily of the tragedy of the commons, seeing only overfishing and overfarming in a free-for-all of greed, Mrs Ostrom, with her loud laugh and louder tops, cut a cheery and contrarian figure.

Years of fieldwork, by herself and others, had shown her that humans were not trapped and helpless amid diminishing supplies. She had looked at forests in Nepal, irrigation systems in Spain, mountain villages in Switzerland and Japan, fisheries in Maine and Indonesia. She had even, as part of her PhD at the University of California, Los Angeles, studied the water wars and pumping races going on in the 1950s in her own dry backyard.

All these cases had taught her that, over time, human beings tended to draw up sensible rules for the use of common-pool resources. Neighbours set boundaries and assigned shares, with each individual taking it in turn to use water, or to graze cows on a certain meadow. Common tasks, such as clearing canals or cutting timber, were done together at a certain time. Monitors watched out for rule-breakers, fining or eventually excluding them. The schemes were mutual and reciprocal, and many had worked well for centuries.

Best of all, they were not imposed from above. Mrs Ostrom put no faith in governments, nor in large conservation schemes paid for with aid money and crawling with concrete-bearing engineers. "Polycentrism" was her ideal. Caring for the commons had to be a multiple task, organised from the ground up and shaped to cultural norms. It had to be discussed face to face, and based on trust. Mrs Ostrom, besides poring over satellite data and quizzing lobstermen herself, enjoyed employing game theory to try to predict the behaviour of people faced with limited resources. In her Workshop in Political Theory and Policy Analysis at Indiana University—set up with her husband Vincent, a political scientist, in 1973—her students were given shares in a notional commons. When they simply discussed what they should do before they did it, their rate of return from their "investments" more than doubled.

"Small is beautiful" sometimes seemed to be her creed. Her workshop looked somewhat like a large, cluttered cottage, reflecting her and Vincent's idea that science was a form of artisanship. When the vogue in America was all for consolidation of public services, she ran against it. For some years she compared police forces in the town of Speedway and the city of Indianapolis, finding that forces of 25-50 officers performed better by almost every measure than 100-strong metropolitan teams. But smaller institutions, she cautioned, might not work better in every case. As she travelled the world, giving out good and sharp advice, "No panaceas!" was her cry.

Scarves for the troops

Rather than littleness, collaboration was her watchword. Neighbours thrived if they worked together. The best-laid communal schemes would fall apart once people began to act only as individuals, or formed elites. Born poor herself, to a jobless film-set-maker in Los Angeles who soon left her mother alone, she despaired of people who wanted only a grand house or a fancy car. Her childhood world was coloured by digging a wartime "victory" vegetable garden, knitting scarves for the troops, buying her clothes in a charity store: mutual efforts to a mutual end.

The same approach was valuable in academia, too. Her own field, institutional economics (or "the study of social dilemmas", as she thought of it), straddled political science, ecology, psychology and anthropology. She liked to learn from all of them, marching boldly across the demarcation lines to hammer out good policy, and she welcomed workshop-partners from any discipline, singing folk songs with them, too, if anyone had a guitar. They were family. Pure economists looked askance at this perky, untidy figure, especially when she became the first woman to win a shared Nobel prize for economics in 2009. She was not put out; it was the workshop's prize, anyway, she said, and the money would go for scholarships.

Yet the incident shed a keen light on one particular sort of collaboration: that between men and women. Lin (as everyone called her) and Vincent, both much-honoured professors, were joint stars of their university in old age. But she had been dissuaded from studying economics at UCLA because, being a girl, she had been steered away from maths at high school; and she was dissuaded from doing political science because, being a girl, she could not hope for a good university post. As a graduate, she had been offered only secretarial jobs; and her first post at Indiana involved teaching a 7.30am class in government that no one else would take.

There was, she believed, a great common fund of sense and wisdom in the world. But it had been an uphill struggle to show that it reposed in both women and men; and that humanity would do best if it could exploit it to the full. ■

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