ADDENDUM TO OUR DYING PLANET TO BRING THE STORY UP TO SEPTEMBER 2012

In early May 2010, I was finalizing the text for Chapter 8 when the Deepwater Horizon disaster was in its early days. Page proofs for the book were getting their final edits when the Fukushima earthquake and tsunami occurred on 11th April 2011. Here I try to bring the story up to date, covering the period up to September 2012.[1] There are glimmers of good news mixed in with an abundance of bad news. Our global environmental crisis has got a little bit worse, our willingness to do something about it has, if anything, declined, at least in North America where the Canadian government appears determined to focus on tar sands extraction as the only motor for the economy, and the US government has been mired in gridlock and the inexorable 18 month grind towards a presidential election (November 2012).

DEEPWATER HORIZON DISASTER

The decision by BP to inject large quantities of the oil dispersant, Corexit, at depth as well as disperse it at the surface had one enormous benefit. The anticipated very visible damage to wetlands and beaches was largely averted along with the mournful photographs of oiled birds that always result. The public was told that visible oil largely disappeared from surface waters just weeks after 15 July 2010 when the well was capped, three months following the 20 April blowout. Knowledgeable individuals report that surface slicks still existed offshore, and visible oil was widely dispersed in deeper water many months after that. Some tar balls still continue to wash ashore, but except when one digs below the surface, the relative absence of easily visible noxious oil on beaches, in marshes, and on birds has quickly removed the disaster from the nightly news.

Altogether, some 4.9 million barrels of oil escaped before the well was capped, and there is some evidence that seeping continues. It was the largest accidental marine oil spill in history, and the slick

[1] Posts on my blog, found on my website www.petersalebooks.com will continue to comment on new events as they occur following September 2012.

extended over 10 thousand km^2 at its greatest extent. What happened to the oil remains a matter of considerable argument, with many scientists seriously doubting the claim by NOAA and BP that 40% of it evaporated from the sea surface. Now, two years after this disaster, its true ecological impacts remain far from clear.

With time, it will become increasingly difficult to demonstrate definitively that particular events were caused by this spill. For example, wetlands in the Mississippi River Delta have undergone chronic degradation due to a variety of natural and human-induced factors. These include the leveeing of the Mississippi River and dam construction upriver, the river's present fixed position, land subsidence from oil and gas extraction and from natural geologic processes, extreme weather conditions such as hurricanes and droughts, arrivals of invasive species, and canal construction for oil and gas activities and for navigation. These impacts caused a 5,400 km^2 loss of wetlands between 1930 and 2010, according to a 2011 US Geological Survey report; the greatest wetland loss in the United States. Distinguish effects of the oil spill from these other causes of degradation is going to be difficult to impossible, and BP will fight in court to minimize the amount of damage which does get attributed (large amounts of money are at stake).

One reason for the lack of clear evidence of ecosystem damage is simply that the accident happened in water 1.5 kilometers deep, and the deep injection of Corexit helped keep much of the oil dispersed in the water column rather than rising to the surface. Scientists simply do not know a lot about the deep-water ecosystems of the Gulf, and monitoring, sample collection, or the mounting of field experiments at those depths is both technically challenging and expensive. Added to this is the fact that much of the research funding that initially went to support scientific investigations was in the form of contracts that carried 'non-disclosure', or at minimum, 'non-disclosure without prior approval' clauses. Such language is not unusual, especially in industry-funded research, but the need to obtain prior approval from BP, NOAA, EPA or some other entity does delay publication, and can lead to serious delay if the data being published are 'sensitive'. A third reason is that ecological processes move at their own pace; one which is often much slower in deep cold water than at the surface. There are still giant plumes of dispersed oil

detectable in the water column, as well as demersal pools of contaminated water in some deep basins. Serious impacts could still reveal themselves some years into the future. A fourth possible explanation is that, for one reason or another, this oil spill, despite its enormous size, has not had significant impacts on the Gulf's ecology.

People who favor this fourth explanation point to the possibility that the heavy use of Corexit may have been precisely the correct action to take, because it dispersed the oil making it much more accessible to microbial scavengers capable of metabolizing it – oil-metabolizing microbes are relatively common in Gulf of Mexico waters. Of course some of the people who favor this explanation happen to work for oil companies and oil-friendly organizations.

Yet the fact remains that an enormous quantity of oil was spilled, and a mixture of Corexit and oil is more toxic than the oil itself. Meanwhile, a steady stream of reports appears in the professional journals documenting distribution and abundance of the remaining oil, effects on microbial communities, and effects on physiology, behavior and ecology of fisheries species, on marshes and their biota. Definitive reviews have not yet appeared, and it may be several more years before we learn the true extent of the damage that was done. The Gulf fishery supplies about 1/3 of the North American seafood market, and 90% of the fishery species harvested depend on estuaries and wetlands as juvenile nurseries. In September 2012, when Hurricane Issac came ashore along the Louisiana and Mississippi coasts, it eroded some beaches exposing extensive patches of oil. As expected, oil samples from Elmers Island and Grande Isle, Louisiana, were positively identified as from the BP blow-out. It is very unlikely that we have seen the last of the bad news about this disaster. Deep-sea drilling continues, and the oil companies continue to assure us that nothing like this disaster will ever happen again.

FUKUSHIMA'S PERFECT STORM

The Tohoku earthquake of 11th March, 2011, a 9.0 magnitude earthquake with its epicenter located offshore and about 130 km northeast of the town of Fukushima, was the largest earthquake ever to hit Japan. It generated a tsunami that inundated much of Japan's coastline, particularly the northeastern

coast of Honshu where wave heights topped 8 meters through much of Iwate, Miyagi, and Fukushima Prefectures, and reached as high as 14 meters in some locations. Damage to coastal towns, cities and harbors was immense and around 15,000 people lost their lives.

At the Fukushima Daiichi nuclear power plant, located on the coast just south of the village of Futaba, the tsunami washed over the seawall and knocked out most of the backup generators crucial for the continued provision of cooling water to the six reactors. Partial meltdowns occurred in the cores of Reactors 1, 2, and 3; at the time of the quake Reactors 5 and 6 were shut down for maintenance. The situation went from bad to worse with several hydrogen explosions, breaching of containment vessels, and releases of radiation into the atmosphere. Efforts to restore power failed, seawater was used in a desperate attempt to cool exposed fuel rods and reactor cores (thereby ensuring the plant could never be restored), and people were evacuated from a 20km radius region around the site. (They were subsequently encouraged to evacuate voluntarily from locations up to 30km away.) Eventually, the overheating was brought under control, but by then the power plant, largest on that portion of Japan's coast, was reduced to a highly contaminated wreck that will take many years to be cleaned up and sealed off. Japan shut down all its nuclear power plants for thorough safety and disaster-preparedness inspections.

While the damage and loss of life due to the earthquake and tsunami were immense, and the radiation danger posed by the failure at the nuclear facility was also serious, this disaster has had two additional important long-term effects on people. The first is a heightened awareness of the importance of having adequate risk-avoidance and risk-management procedures in place in such facilities, and the importance of openness and transparency by management and government when an accident occurs. It was apparent early on that both TEPCO (Tokyo Electric Co.) and the Japanese government, reminiscent of the Soviet managers of Chernobyl 25 years earlier, were being evasive and slow to respond to concerns by society in the days and weeks following the accident. Now, it is also apparent that TEPCO had done a risk analysis which indicated the advisability of strengthening and raising the sea wall, but had not acted on it. Japan's Nuclear and Industrial Safety Agency had reviewed TEPCO's risk-management plans as well as the

risk analysis results, but did not require TEPCO to take action. Fukushima Daiichi was simply not being managed at accepted international safety standards. The habit of secrecy, by both TEPCO and Japanese government, revealed in the days following the tsunami, permitted the inadequate standards to remain in place because all assumed TEPCO was operating responsibly. There are many reasons for openness in government and large corporations – safety is one of them, and Fukushima Daiichi may lead to renewed efforts to achieve such openness in Japan and elsewhere.

The second effect on people was a sudden chilling worldwide of the growing acceptance of nuclear power as an appropriate source of energy for our growing economies. Within Japan, all 54 commercial reactors were shut down following the accident and only two have been restarted to date. Japan, a leader in use of nuclear energy, is now deeply divided over whether it should use nuclear power at all. The loss of electrical generating capacity has been made up by increased use of fossil fuels, at considerable economic cost given Japan's virtual lack of fossil fuel resources of its own. Around the world, those who opposed nuclear power have been handed new ammunition and are again winning arguments that they had begun losing. In March 2012, The Economist headed an article "Nuclear power. The dream that failed" in which it reported that the persistent high costs of building and operating reactors, coupled with the renewed concerns about safety will have a lasting effect that will delay any ramp-up, and will probably lead to a down-turn in the proportion of energy derived from nuclear power. Given our need to reduce dependence on fossil fuels and our unwillingness to consider a world which uses less energy, the Fukushima event was a disaster for everyone. I remain convinced that we are going to have to use nuclear power in the transition away from fossil fuels, but I also recognize that any shift towards nuclear has been slowed to a stop.

CURRENT TRENDS IN ENERGY USE AND GREENHOUSE GAS EMISSIONS

Ironically, the global economic downturn, which began in 2008, and continues to cause economies throughout the world to sputter and stall, only marginally slowed our releases of greenhouse gases. According to the IEA, the release of greenhouse gases (GHGs) from burning of fossil fuels declined by 1.5%

in 2009, but in 2010 emissions increased by 5.9%, and a further 3.2% increase in 2011 brought the global total to 31.6 gigatonnes. Developing countries now emit more CO_2 than do developed countries, and the reason is of course that the rates of growth of their economies and the related growth in need for energy greatly outstrip any slow-down in developed countries. While there has been substantial growth in the use of alternative energy sources, our overall use of fossil fuels has continued to grow.

The BP Statistical Review of World Energy, published in June 2012, reports that world energy use grew 2.5% in 2011, and that oil continued to be the most important fuel source although its fraction of total energy consumption (33.1%) was the lowest since records commenced in 1965. While use of energy derived from renewable sources other than hydropower had grown an impressive 17.7%, these sources supplied only 184.6 mtoe (million tonnes oil equivalent) worldwide in 2011 of the total of over 12,000 mtoe energy use – a scant 1.5% of the total. The use of hydropower was almost static at 791.5 mtoe. What has been happening is that while developed countries have been shifting marginally away from fossil fuels and showing only marginal if any increases in energy use, developing countries with rapidly expanding economies have been rapidly increasing their use of energy and using fossil fuels as the primary source. In 2011, China recorded a 5.5% increase in its use of oil, a 21.5% increase in use of gas, and a 9.7% increase in use of coal to accommodate an overall increase in use of energy of 8.8%. The use of coal worldwide jumped to 3,724 mtoe, an increase of 5.4% over 2010.

This overall increase in use of fossil fuels, and the shift towards greater reliance on coal, ensures that the concentration of CO_2 in our atmosphere is continuing to grow, and at an increasing rate. We remain on track to exceed the worst case predictions made by IPCC in their 4^{th} (2007) assessment. Given the sluggish economies in much of the world since 2008, and the fact that there have been efforts by the multinational community since 1992 to rein in greenhouse gas emissions, these results for use of fossil fuels in 2011 must be considered particularly disappointing. In June 2012, the CO_2 concentration above Mauna Loa was 395.77 ppm.

THE BATTLE FOR HEARTS AND MINDS OVER CLIMATE CHANGE

In *Our Dying Planet*, I wrote of the change that took place across Australia in the 1970s as the combination of a collision by the tanker, *Oceanic Grandeur*, with a pinnacle off Cape York, a decision to open the Great Barrier Reef to oil exploration, and a campaign by a tiny NGO came together to change public opinion concerning the value of the Great Barrier Reef. The change was widespread, it was rapid, and it was exhilarating. It led to the creation of the Great Barrier Reef Marine Park, and to the strong belief by Australians in the iconic value to their nation of this amazing place. I remarked that this kind of transformation is what is now needed on a global scale if we are to confront the environmental crisis successfully. I mused about what might trigger such a transformation, and wondered if we might need the jolt of a mini-disaster to get us started. I am still waiting.

The fraction of the American public "believing in" climate change has remained remarkably constant since 2009. The same is true in Canada and in Britain. While different polling studies reveal slight fluctuations in attitude, and can attribute these to effects of the economic downturn, weather over the past season, or extent of discussion/debate on climate issues in the political sphere, there is a remarkable overall rigidity in attitudes. An Angus Reid poll conducted in May and June 2012, in the USA, Canada and Britain reported that on six occasions from November 2009 to May 2012, when asked whether they agreed with the statement "global warming is a fact and is mostly caused by emissions from vehicles and industrial facilities" 41 to 49% of American respondents said they did. The same statement was supported by 38 to 47% of British respondents, and by 52 to 63% of Canadian respondents. The only consistent pattern in the data was that Canadians seem more willing to accept the reality of climate change than either their U.S. or British cousins. Perhaps Canadians really are a more rational community?

A 2012 report from the Brookings Institute, based on the National Survey of American Public Opinion on Climate Change, provides interesting insight into the rationales used by Americans for their beliefs. In response to a question about whether the respondent believed climate change was occurring (regardless of cause), 72% said 'yes' in Fall 2008, but that proportion had fallen to 52% in Spring 2010, 58% in Fall 2010, and 55% in Spring 2011, before rising to 65% in Spring 2012. Those answering 'no' ranged from 17% in Fall 2008 to 36% in Spring 2010, but fell back to 24% in Spring 2012. However, when the survey

probed the reasons for these beliefs, respondents who said that climate change was not occurring gave quite different responses in different years. In Fall 2008, 42% of these respondents cited personal experience of weather as the primary factor influencing their opinion. A further 19% stated they expected natural cycles in climate. In Spring 2012, following a particularly mild winter, while the number with faith in natural cycles was essentially unchanged, only 20% of respondents claimed personal experience as the primary influencing factor, and 10%, 10%, and 9% respectively claimed evidence (unspecified) against climate change, religious factors, and the idea that climate change is a partisan political argument as the primary factor influencing their views. My assessment of the various polls is that the segment of society in each of these countries that can be persuaded by scientific data has been convinced some time ago, and the segment that cannot be persuaded in that way remains convinced that climate change is not real. When asked why they hold particular views, those who deny the reality have reduced their reliance on personal experience of weather as weather has grown more extreme, and instead rely on other factors. By contrast, those who believed that climate change was real reported they increased their reliance on personal experience of weather as weather became more extreme through to 2012.

People have beliefs; they choose as justifying reasons those data that best support those beliefs, and they do not all choose in the same way. Despite the growing scientific evidence of climate change, and despite the growing evidence of weather suggestive of climate change, people's individual belief systems are proving remarkably resistant to being altered. And the environmental movement has not succeeded in finding a way to break through to those who stubbornly continue to deny change is happening. Why is that so?

I believe there are three broad groups of people in countries such as the US, Canada and Britain who continue to deny the reality of climate change. First are those who cannot accept such ideas because of fundamental beliefs, frequently but not always religiously based, in the essential stability of the universe. Some refer to this as a belief in the inherent balance of nature, while others cannot accept a world in which God does not keep us safe. Second are those who do not want to accept the possibility that climate change is occurring because their own personal success depends on continuation of business as

usual, including a growing economy based on use of fossil fuel. Some of these may be directly engaged in the energy sector, while others have a world view that is based on continuation of the status quo which has always permitted them to prosper in the past. Third are that small group of people who recognize that the evidence in favor of climate change is compelling, but are determined to argue against this possibility, even deliberately providing misinformation in order to obfuscate and confuse the public. These individuals are not all employed by mining corporations, but nearly always stand to benefit directly from continuation of the status quo. They are willing to distort evidence, or allude to political motives among those who argue in favor of climate change, simply in order to muddy the waters. These "deliberate deniers" are following the same strategy that was so successful for tobacco companies over so many years as evidence of the link between cigarettes and cancer grew, and there is accumulating evidence that their activities are at least partially coordinated. Their efforts have unfortunately been aided by a media that seems to think that 'balanced reporting' means giving equal time to two sides of every argument no matter where reality lies.

Each of these three groups, for very different reasons, continues to deny while the environmental movement seemingly wastes time providing ever more evidence that is not being weighed. I suspect it is past time for those trying to alter public opinion in favor of the reality of climate change to develop new messages targeted explicitly to each of these three groups of deniers. An alternative approach is to bypass the hoped-for groundswell altogether, and target key decision-makers directly.

Creating a groundswell of public opinion is one way to effect change in a democracy, although it can be less successful in other types of society. The crucial goal, in all societies, is to change the attitudes and therefore the behavior of ruling elites. Three recent publications suggest the environmental movement is not being successful either in creating this groundswell or in reaching ruling elites by other means, but they also point to some possibly fruitful new approaches to try.

On July 13th, 2012, Roger Bradbury, an Australian ecologist, published an Op-Ed piece in The New York Times. Deliberately timed to coincide with the 12th International Coral Reef Symposium wrapping up that

day in Cairns, Australia, Bradbury chastised his colleagues for providing the public with "an airbrushed view" of the future of coral reefs. According to Bradbury the view largely endorsed by the reef science community, along with environmentalists and the NGO community, is that coral reefs are "existentially threatened – but salvageable" and "there is yet hope". Bradbury argues that coral reefs are on a trajectory to collapse within a human generation, and that to deny this fact wastes precious time and resources which should be used to do the research needed to salvage what we can of goods and services after the reefs that have traditionally provided them have gone. Bradbury's article runs counter to the prevailing view in the coral reef community that it is important to focus on the few glimmers of good news, in order to give people hope and the motivation to continue working to sustain coral reef systems.

On July 19th, environmental activist Bill McKibben published an article in Rolling Stone in which he pointed to three numbers, 2°C, 565 gigatonnes, and 2,795 gigatonnes, and claimed the global fossil-fuel companies as Public Enemy Number One. In late 2009, 167 countries signed the Copenhagen Accord which, while essentially toothless, did include acceptance of 2°C of warming as the maximum to be tolerated (despite the fact that many scientists now fear this is dangerously large). Given that we have already raised mean temperature about 0.8°C, scientists estimate we can emit about 565 gigatonnes of CO_2 by mid-century and remain within the 2°C limit. However, at the rate we are using fossil fuels, we will reach this limit in 16 years. McKibben's third number, 2,795 gigatonnes CO_2 is the really scary one. It's the amount of CO_2 that will be emitted if we extract and use all current proven reserves of fossil fuel – the known amounts on which the economic valuations of energy corporations are based. Fossil fuel corporations have many motivations to extract and sell their reserves, thereby providing value for their shareholders; McKibben argues that it will be very difficult to divert them from this course, but divert them we must. Using all proven reserves is not compatible with a livable planet.

On 4th August, 2012, an article by climate scientist James Hansen and others was published in the prestigious Proceedings of the National Academy of Sciences. Unlike previous articles by Hansen's team, this one uses real-world weather data rather than sophisticated climate models to look for evidence that climate change is taking place. They provide compelling evidence that the worldwide frequency of

extreme warm events has increased dramatically since 2005, vindicating a prediction they made in 1988, based on climate models. Their argument: climate change is already with us, and we can see it in unusual weather.

These three articles share a frustration with the fact that, despite growing evidence of the reality of climate change, and the seriousness of its effects, we are not yet seeing demands for real action by the global community to stem the emissions of CO_2. Bradbury expresses this frustration as anger with the science community for sugar-coating their message about the peril of coral reefs; McKibben and Hansen take new stabs at providing yet more evidence that the climate problem really is serious. McKibben's declaration that the fossil fuel energy industry is "the enemy" is not new, but is more explicit and may galvanize some action by the public. Overall, though, I doubt these three efforts will bring new converts (Bradbury's dose of cold water might even turn some committed supporters away).

On the other hand, further documenting the seriousness of consequences from continuing a business-as-usual approach could further energize those members of the public that are already committed, and singling out the fossil fuel energy industry helps separate this set of committed deniers from other groups that may yet be persuaded. A greater effort to publicize the evidence of coordinated campaigns in favor of the status quo, and to trace and record the amounts of money flowing to support such campaigns could help discredit the arguments being used[2]. And finding new ways to convey effectively the economic and human costs of continued business-as-usual might persuade government leaders that a changed course is necessary. Throughout, it will be important for scientists to remain objective and dispassionate about the data they present, but this is not incompatible with being clear advocates for reducing the use of fossil fuels. It will also be important to continue to move the discourse out of the environmental

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[2] The Heartland Institute has come under some scrutiny in 2012 as a leading member among groups that seek to distort or confuse the evidence concerning climate change. This non-profit think tank had some confidential papers leaked which revealed the extent of its support for known climate deniers, and some of those who support its work financially. Googling the institute usually pops up interesting stories. SourceWatch provides a balanced summary: www.sourcewatch.org/index.php?title=Heartland_Institute

journals and into the mainstream media, and to seek experts from other disciplines than the natural sciences. Potential allies in conveying economic arguments to government may be found among the leaders of the insurance industry who are surely cognizant of the growing difficulty of assessing risk in a world with a rapidly changing climate. As I just said, I am still waiting to see the groundswell of opinion in favor of acting to stem climate change. But I remain optimistic that it will come soon.

OTHER IMPACTS ON ENVIRONMENT

POPULATION

The world's human population reached 7 Billion late in 2011. The United Nations used 31st October as the date on which this milestone would be reached (it is not technically possible to know precisely the exact size of the global human population; 31st October was a date that conformed to the median estimate of population size by UN statisticians). Media coverage of this event centered on photos of various new-born children in developing countries, and stories that spoke of the difficulties faced by poor people worldwide – lack of food or water security, impoverished lifetime opportunities, degraded and polluted environments, lack of access to medical care. Paradoxically, television and the web media used the photos of the children to turn the story into a birthday celebration for the 7 billionth human being, and turning the story from the UN completely on its head in the process. So, little has changed. There is still a reluctance to discuss population growth as the problem it is, and most people treated the milestone as not of any great importance. The greatest rates of growth of the human population are in those poorer developing countries that will have great difficulty combatting the impacts of other forms of global change. Rapidly growing populations make their chances of success even weaker than they would otherwise be.

ALL THE LOCAL ANTHROPOGENIC IMPACTS ON THE BIOSPHERE

The passage of a year or so does not lead to major changes in our overuse of forests or fisheries, our pollution of air, soil and water, our inadvertent release of invasive species, or our continuing reductions of biodiversity around the world. FAO, the Food and Agriculture Organization of the United Nations released

its 2012 edition of The State of World Fisheries and Aquaculture which showed that capture fisheries globally had remained essentially static between 2006 and 2011, at 90 million tonnes, with a slight trend towards increased yield from fresh water and a declining yield from marine fisheries. Overall fishery and aquaculture yield has continued to grow (154 million tonnes in 2011) primarily due to increases in inland aquaculture. Global per capita fish consumption is estimated as 18.6 kg in 2010, up marginally from 18.4 kg in 2009. FAO states that 57% of marine fishery stocks were fully exploited in 2009, 29.9% over exploited, and only 12.7% under-exploited and capable of yielding larger catches sustainably in the future. These numbers indicate continued deterioration, and for the first time words like 'worrisome', 'worsening', and 'depleted' crop up regularly in the text.

On 24 June 2012, Lonesome George died. Lonesome George was the last surviving member of the species *Chelonoidis abingdoni*, a tortoise native to Isla Pinta, in the Galapagos. He had lived at the Charles Darwin Research Station since 1971. I saw Lonesome George in early 2011. To my untrained eye, he looked like any other Galapagos tortoise – the tortoises from different islands look quite similar but are distinct enough that 15 species were originally recognized. With his death, only 10 species remain. While he was well cared for and died apparently of natural causes, the losses of species of Galapagos tortoise have been due to over-exploitation, habitat destruction, and introduction of exotic species such as rats and goats – a familiar tale in the annals of biodiversity loss. The IUCN Red List continues to be updated as species edge closer to extinction, and there are no signs that the rate of this loss of species is slowing down. If you plot the global WWF Living Planet Index[3], as Camilo Mora and I did in a paper we published in the journal, Marine Ecology Progress Series, late in 2011, you discover a nearly linear steep downward trend for terrestrial systems since 1970, and a similarly steep downward trend for marine systems since 1990. Biodiversity continues to fall.

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[3] The Living Planet Index (LPI) is an index of biodiversity based on trends in over 8,000 separate populations of 1,800 species of fish, amphibians, reptiles, birds, and mammals worldwide. It is maintained and updated regularly by the Zoological Society of London for WWF, and is recognized by the Convention on Biological Diversity. The global LPI has fallen 27% between 1970 and 2005.

In June 2012, Anthony Barnosky of UC Berkeley, and a group of colleagues from his own and other premier universities in the US and elsewhere, published a thought-provoking article in the journal Nature. In it, they discussed the possibility of what they termed a planetary-scale state shift caused by our growing impacts on the natural world. State shifts or phase shifts are known to occur within ecological systems, and appear as a relatively sudden change of state following a period of growing stress.

In *Our Dying Planet*, I discussed the phase shift that has taken place on a number of coral reefs, especially in the Caribbean, when overfishing and other factors have led to a substantial reduction in herbivory. Under reduced herbivory, algae become much more conspicuously present, and shade out existing, while obstructing the recruitment of young coral colonies. Over a short time span of months to years, the reef goes from a strongly coral-dominated ecosystem in which algae other than filamentous turfs are almost absent, to an algal-dominated system in which numerous species of macroscopic algae such as *Sargassum* and *Turbinaria* are prevalent while corals occupy as little as 2-5% of the substratum.

Barnosky and colleagues are talking about transformations of this magnitude but on a planetary scale, comparable to the transition that occurred at the end of the Pleistocene, or those that ushered in each of the five mass extinction events since the Cambrian period. A state shift of such magnitude would have very serious repercussions for our economy, our way of life, and even our survival.

That *Nature* published this article tells us a lot about how the ecological community is viewing the situation we find ourselves in in 2012. As Bernosky and colleagues point out, the world now faces powerful global-scale forcings in the form of human population growth and growth in per capita rates of consumption of environmental goods and services. These in turn generate additional global forcings in the form of habitat transformation and fragmentation, energy consumption, and climate change. Rates of all of these are already greater than at any time during the Pleistocene-Holocene transition, and current trends in human population growth, economic growth, and energy consumption indicate that all are becoming more severe. How close are we to a possible global-scale state shift, and what can we do to

anticipate, and even to act to avoid it? That such questions are being seriously asked shows we indeed live in troubled times.

Already, 43% of the Earth's land surface has been converted to agriculture or urban centers. Humans commandeer 20-40% of net primary production on the planet, thereby channeling a substantial proportion of biological activity through a single dominant species (us). We use energy at a rate equivalent to the burning of 12 billion barrels of oil annually, and we indeed burn oil and other fossil fuels to supply the great proportion of this energy. The by-products of our activities lead to growing problems with pollution of air, land and water, leading in turn to the suite of issues called climate change and ocean acidification. As I documented in *Our Dying Planet*, there is more and more evidence that the biosphere is being changed in many ways by our presence and our activities, and the trends all point to a situation that will get worse.

THE STATE OF THE OCEANS

In *Our Dying Planet*, I suggested that ocean acidification might become as serious a problem as climate change itself, but that we did not yet know enough about its impacts. I also pointed to two other problems for the ocean driven by climate change effects: deep ocean anoxia and slowing down of major current systems including the ocean conveyor that circulates water through the deep ocean basins. In subsequent months, the oceans have gained more prominence in IPCC deliberations and other venues, and a growing body of scientific information has accumulated.

Scientists investigating ocean basin-scale phenomena like deep anoxia or slowing of current systems continue to raise the alarm, but definitive evidence of major changes is not yet available. Still comparisons to ancient events, such as the profound alterations to ocean chemistry during the end-Permian mass extinction, or the more recent transition from the Paleocene to the Eocene, are being explored for possible insights they might bring to current assessments.

In early 2012, Richard Zeebe of the University of Hawaii published a paper in Annual Reviews of Earth and Planetary Sciences in which he reviewed the geological history of oceanic carbonate chemistry,

atmospheric CO_2, and ocean acidification. He reported that the acidification event that we expect to cause over the next decades is unprecedented over a period extending back to the Permian.

His exact words were, "It appears that the ocean acidification event that humans are expected to cause is unprecedented in the geologic past, for which sufficiently well-preserved records are available". The wiggle-words here are 'for which sufficiently well-preserved records are available', because as geoscientists go back in time the ability to measure such things as ocean pH with high precision has to decline. His statement certainly holds true for the 65 million years of the Coenozoic period, that time since the end Cretaceous mass extinction and the end of the dinosaurs (plus a whole bunch of other creatures). His statement probably also holds true for the Mesozoic, and perhaps even further back, beyond the Permian mass extinction. We are doing something unprecedented to the ocean.

In what ways is the current acidification episode unprecedented? In its extent and its rate. Understand that the CO_2 is dissolving from the atmosphere into the surface layers of the ocean. Surface waters are typically warmer (and a bit more saline) than deeper waters, and their relative warmth keeps them floating above, and mixing only slowly with layers of deeper water. The CO_2 concentration in the surface waters can equilibrate very rapidly with that in the atmosphere, but equilibration with deeper oceanic waters takes ~1000 years, because the processes by which the world's oceans overturn their water is a very slow one. Incidentally, the warming of surface waters may also act to slow down further the overturning of oceanic water, thus extending the time it will take to mix surface and deeper waters.

If we look at ocean chemistry during the Holocene, that 10,000 year period from the end of the Pleistocene glaciation to the present, ocean chemistry has been remarkably stable until very recently. Atmospheric CO_2 varied between about 260 and 280 ppm throughout this time, but began to rise higher with the onset of the industrial revolution. It was at 315 ppm in 1958, and is at 394 ppm today. The variation of about 20 ppm over 10,000 years is far less than the 100 ppm over the last 150 years. Not surprisingly, ocean pH was also remarkably stable over these 10,000 years, although it has been decreasing recently. Zeebe states that pH declined about 0.04 units during the Holocene, but since 1750

has fallen 0.1 unit. He estimates that, under business-as-usual energy policy, it will decrease by 0.7 units by 2300 – a rate that is about 300 times faster.

Looking back beyond the Holocene, Zeebe notes that the current rate of acidification is about 70 times faster than the brief episodes of acidification that accompanied each of the deglaciation phases during the Pleistocene. He states that surface water pH was lower during the early Coenozoic, pH of ~7.6, and rose very slowly, with possible short-term fluctuations at times of substantial planetary change such as the Paleocene-Eocene boundary, towards the pre-industrial range of pH = 8.1.

Zeebe concludes by examining specific events during the Coenozoic and the more distant past to see if there are short-term changes that may correspond to what is happening today. Of various events, he identifies the Paleocene-Eocene Thermal Maximum, or PETM event, as perhaps the closest analog to what is now happening. The Paleocene-Eocene boundary was a time of substantial vulcanism, and the PETM event has several characteristics in common with what is happening today. First, it was a time of substantial injection of CO_2 into the atmosphere, and from there into the surface layers of the ocean. Second it was a transient event, not a long-term steady-state situation when the surface and deeper waters would have come into equilibrium. It also is a relatively well-studied event from geological, oceanographic and paleontological perspectives. Nevertheless, it is not the same as what is now happening. The difference is primarily one of rate of change. Zeebe has previously estimated that during the PETM event, about 3,000 peta-grams of carbon (that's 3000×10^{15} grams) were released into the atmosphere over 6,000 years. Under business-as-usual projections, we are likely to release 5,000 peta-grams of carbon over the 500 years since the start of the industrial revolution (1750 to 2250).

So putting all this together, the present episode of acidification appears unique over at least the last 65 million years in both the magnitude and the rate of change of CO_2 concentrations. And it follows a period of at least 10,000 years of essential stability. Perhaps it should not surprise us that biologists are now detecting a growing range of impacts on organisms and on biological processes, caused by these changes to ocean chemistry. These effects include the impacts on the calcification process that I discussed in *Our*

Dying Planet. But in addition to these, a broad range of impacts are being identified that act on other aspects of biology. There are changes in behavior in some species, difficulties in completing the transition from larval life to settled adult life by various invertebrates, and problems with fertilization and embryonic development in still others. None of these effects should be surprising – pH has been a remarkably consistent characteristic of sea water for a very long time, and modern changes to it are therefore substantially new.

The effects of ocean acidification are now reported to be having economically significant impacts on the giant US West Coast oyster fishery. The State of Washington provides about 1/3 of the oyster production for the US, and the industry providing these oysters is worth about $111 million per year. Reproductive failures had been seen in 2006, 2007 and 2008, and oyster farmers began to suspect that something other than 'bad years' was responsible. The data developed so far are not definitive, but it appears that acidification of ocean waters off this coast are partly or largely responsible. Just one more example of how our effects on our environment are increasingly coming back to bite us.

AND WHAT ABOUT THE WORLD'S CORAL REEFS?

In *Our Dying Planet* I wrote, "Worldwide, reefs have deteriorated measurably in my lifetime, and it is not an unrealistic prediction to say that we risk having no reefs that resemble those of today in as little as thirty or forty more years. None". Later in the book I wrote, "I am optimistic that we will ultimately address greenhouse gases, sufficiently to mitigate many of the effects of climate change, but I seriously doubt the world will respond quickly or forcefully enough to prevent climate change from going beyond the point at which reefs cease to exist in any form resembling the reefs of the 1970s". So, I said it at least twice, and quite definitively. 'Thirty or forty more years' means ~2050. I would love to be able to report that I was wrong, and that reefs are going to be saved, but my perspective has, if anything, become more negative. There are few signs that we are moving more effectively to solve the local problems that affect all reefs, and we certainly are not making progress on our global problems.

What is new is that we have more evidence of just how extensive the decline has already become, and we have growing understanding concerning how corals and coral reefs respond to the various stressors we hurl at them. The International Coral Reef Symposia are a series of conferences of coral reef scientists and managers that occur every fourth year. The 12th such event took place in Cairns, Australia from 9th to 13th June, 2012. About 2000 people came from 80 countries to take part. These conferences have become the premier location for gatherings of reef scientists, and attending one is a good way to take the pulse of this community.[4] I commented earlier on Bradbury's op-ed article in the New York Times. In Cairns I heard many scientists speaking with real concern about the state of reef decline worldwide, although they mostly avoided saying what Bradbury said – the reefs are doomed. Most of us recognize that there remains a slim chance that coral reefs will slip through this time of risk and prosper once more, but we also know it's an increasingly slim chance.

Some of the results reported at Cairns revealed the true extent of loss of coral reefs already. While accounts of reef decline in the Caribbean have been numerous, I was particularly impressed (discouraged) by information from the Great Barrier Reef, a reef region that has been well managed since the early 1980s. Several speakers referred to an analysis of data from the Australian Institute of Marine Science that was wending its way through the peer-review process and therefore not yet publicly available. These data result from the AIMS long-term reef monitoring project that commenced in 1985.

That paper appeared on-line at the site of the respected journal, Proceedings of the National Academy of Sciences of the United States (PNAS). It reports an analysis based on 27 years of data collected from the length and breadth of the Great Barrier Reef (a region of coastal seas littered with coral reefs and stretching about 1500 km in length while averaging about 150 km wide). A suite of over 300 reefs distributed throughout the Great Barrier Reef region have been randomly sub-sampled on an annual schedule so that some reefs in each region of the Great Barrier Reef are sampled each year. Sampling

[4] That the 12th took place this year tells you how young coral reef science is – the 1st symposium saw 50 scientists gather at Mandapam Camp, India in 1969.

consists of towing divers on manta boards around the complete perimeter of each sampled reef recording extent of coral cover and other environmental information. Additional more detailed data are collected from sites on a subset of the reefs sampled each year. The data in the PNAS article are derived from 2,258 surveys of 214 reefs from 1985 to 2012. Over the 27 year data set there has been a clear downward trend in the extent of coral cover, such that about 50% of coral cover has been lost. For the Great Barrier Reef as a whole, the percentage of the substratum covered by living coral has fallen from 28.0% in 1985 to 13.8% in 2012. This is a loss of 0.54% per year for a total loss of 50.7% during the 27 years.

The declines have differed among different regions of the Great Barrier Reef, and have been due to different causes on different reefs and different years – not a surprising result given the size of the Great Barrier Reef. The main causes? Outbreaks of crown-of-thorns starfishes, cyclone (hurricane) damage, and bleaching due to climate change account respectively for 42%, 48% and 10% of the total loss recorded.

The crown-of-thorns starfish, *Acanthaster planci*, is a naturally-occurring coral predator, but, like many other echinoderms, it occasionally erupts producing dense aggregations that strip all living coral from a reef, and has done so several times on the Great Barrier Reef since the 1960s. While there remains some uncertainty in the science community, the prevailing view is that the prevalence of this species in recent years has been caused by human land use practices that lead to more nutrients entering coastal waters particularly during wetter years. These conditions favor survival of larval starfish and result in very large populations of juvenile starfish that then proceed to eat most available coral before their numbers decline. Estimates are that eruptions of the starfish probably occurred once in 50 to 80 years prior to European settlement of Australia, but that the rate now is once in 15 years. While some damage due to the starfish occurred in every year of the study, starfish-induced mortality was particularly prevalent during 1986-1991, and 2000-2003.

Cyclones have always occurred along the Great Barrier Reef, and can do a lot of local damage if they arrive during periods of favorable tides. Four of Queensland's five most intense cyclones ever recorded

have occurred since 2000, and one of these, cyclone Hamish, travelled slowly south-east along two-thirds of the length of the reef causing damage over a wide swath instead of crossing it and moving onto land as the majority do. One consequence of climate change is an increased intensity of tropical storms, so, in a sense, the damage caused by these recent intense cyclones is also a consequence of human activities. Damage due to cyclones was recorded in nearly all years, but particularly in 1989-1992, 1997-2001, and 2009-2011.

Bleaching, as I discussed in Our Dying Planet, is a stress response of corals that can be triggered by periods of warmer than usual water temperature. The stress of the warmer conditions causes the corals to expel their symbiotic algae, thereby losing all color and appearing bleached. When the stressful conditions persist for three weeks or so, the corals usually die. There was modest mortality due to bleaching in the central Great Barrier Reef in 1997, and there has been extensive mortality due to bleaching at sites along the Great Barrier Reef in 1998, 1999, and 2001-2003. Putting these three causes of mortality together, we see significant losses that have been caused at least partially by human activities. Based on likely projections of our behavior into the future, this mortality is expected to continue and grow more pronounced.

So, what is the chance that coral reefs survive the Anthropocene? I personally have to believe that the jury is still out. It remains possible that the evidence of warmer and more violent weather, melting of the Arctic, loss of coral reefs, failing crops, and shortages of water and food for millions of people will eventually cause governments and communities to move more strenuously than they have until now to reduce our emissions of greenhouse gases. We might become sufficiently frightened that we move quickly and intelligently enough to keep temperature increases closer to 1^{o}C than to the 2^{o}C Copenhagen target, or to the 4^{o}C increase that current trends are pointing towards.

It is also possible that the economic collapse that began in 2008 is not a cyclical event, but the start of a new economic environment for the world. Although use of fossil fuels barely dipped during the depths of the recession, and has recovered completely, the fuel being used is more expensive every year, and with

stagnant economies and massive personal and governmental debt, people are not going to be able to keep using fuel the way they used to. This scenario is not very attractive for us – I do not know how China will keep expanding the options for its people, or how the U.S. and some other wealthy countries will continue the high-consumption lifestyles they have been leading if the global economy continues slack. But if we are unable to afford to pay for the fuels that exist, the rate of emissions will have to fall. This will be good news for the coral reefs, but not very good news for us. A planned transition out of fossil fuels is much to be preferred over a collapsing world economy and the misery that will bring. And there also remains the horrible possibility that humanity, greedy and blind to the consequences, will continue along a path of ever more energy use, primarily using fossil fuels, until we create a world that will be very different to the one we have known. Icarus did not fall back to Earth until he got close enough to the sun to have his wings burned. I truly hope humanity has learned some lessons about humility in the centuries since the time of ancient Greece.

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DEEPWATER HORIZON DISASTER

NOAA has archived reports, publications, data, and public information brochures concerning the Deepwater Horizon incident at http://www.noaa.gov/deepwaterhorizon/

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My information on tar balls exposed by Hurricane Issac came from an article in Business Week, published on 6th September 2012: http://www.businessweek.com/ap/2012-09-06/apnewsbreak-tests-confirm-oil-came-from-bp-spill

THE AFTERMATH OF FUKUSHIMA NUCLEAR DISASTER

My information on the Fukushima disaster is based on a number of media reports and on-line sources. In particular an article in The New York Times by James M. Acton and Mark Higgs, published 9th March 2012, provided information about what happened and drew conclusions suggesting the accident could have been avoided if plant management had been at top international standard. This article is at http://www.nytimes.com/2012/03/10/opinion/fukushima-could-have-been-prevented.html?_r=0

Also in The New York Times:

- a 5th July 2012 article reported on results of the government enquiry that suggested the accident could have been avoided (http://www.nytimes.com/2012/03/10/opinion/fukushima-could-have-been-prevented.html?_r=0)
- a special feature on Japan, published published 28th September 2012, yielded additional background. http://www.nytimes.com/2012/07/06/world/asia/fukushima-nuclear-crisis-a-man-made-disaster-report-says.html?hp

The article cited from The Economist, *Nuclear power. The dream that failed*, was published 10th March 2012, and is available at http://www.economist.com/node/21549936

UPDATE AND CURRENT TRENDS IN ENERGY USE AND GREENHOUSE GAS EMISSIONS

The update provided is based substantially on information available in the BP Statistical Review of World Energy, June 2012, the International Energy Agency's World Energy Outlook 2011, and the U.S. Energy Administration's International Energy Outlook 2011. As well, I used two additional products from IEA: Golden Rules for a Golden Age of Gas, published May 2012, and CO_2 emissions from fuel combustion. Highlights 2011. These articles are all available from the respective websites:

http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481

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THE BATTLE FOR HEARTS AND MINDS OVER CLIMATE CHANGE

The Angus Reid poll discussed here is available at http://www.angus-reid.com/wp-content/uploads/2012/06/2012.06.27_Climate.pdf

The Brookings Institution report of the results of the 2012 National Survey of American Public Opinion on Climate Change is at http://www.brookings.edu/research/papers/2012/06/11-climate-rabe-borick

The three attempts to sway public opinion that I discussed are also all available on-line. Roger Bradbury's 13th July 2012 Op-Ed piece in The New York Times is at http://www.nytimes.com/2012/07/14/opinion/a-

world-without-coral-reefs.html. Bill McKibben's 19th July 2012 article in Rolling Stone is at http://www.rollingstone.com/politics/news/global-warmings-terrifying-new-math-20120719. The citation for Hansen's article is:

Hansen, J., Mki. Sato, and R. Ruedy, 2012. Perception of climate change. Proc. Natl. Acad. Sci., 109, 14726-14727, E2415-E2423, doi:10.1073/pnas.1205276109.

It can be accessed at http://www.pnas.org/content/early/2012/07/30/1205276109.full.pdf

OTHER IMPACTS ON ENVIRONMENT

My quick review of where we are touched on a few specific items. FAO's latest State of World Fisheries and Aquaculture, 2012, is available from their website at http://www.fao.org/docrep/016/i2727e/i2727e00.htm

The death of Lonesome George, the last of the Pinta Island tortoises, was widely covered by the media. Here are links to stories in The New York Times and The National Post: http://www.nytimes.com/2012/07/03/science/death-of-lonesome-george-the-tortoise-gives-extinction-a-face.html?_r=0

http://news.nationalpost.com/2012/06/25/giant-tortoise-lonesome-georges-death-leaves-the-world-one-subspecies-poorer/

The wider issue of biodiversity loss is monitored by the IUCN Red List of Species, at http://www.iucnredlist.org/ and by the WWF Living Planet Index. The index features in the latest Living Planet Report, for 2012, available for download at http://awsassets.panda.org/downloads/1_lpr_2012_online_full_size_single_pages_final_120516.pdf

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STATE OF THE OCEANS

I based the comments on ocean acidification extensively on a recent review by Richard Zeebe:

Zeebe, R.E., 2012. History of Seawater Carbonate Chemistry, Atmospheric CO_2, and Ocean Acidification. *Annual Review of Earth and Planetary Sciences* 40: 141-165.

My information on recent reproductive failures in oysters cultivated in the Pacific Northwest (USA) were based on a report in Science Daily, that was picked up by The Huffington Post and other outlets:

http://www.sciencedaily.com/releases/2012/04/120411132219.htm,
http://www.huffingtonpost.com/2012/04/13/ocean-acidification-oysters_n_1423731.html

STATUS OF CORAL REEF

The report on the loss of coral cover on the Great Barrier Reef is currently available on-line at http://www.pnas.org/content/early/2012/09/25/1208909109

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