1. Introduction

Let us not delude ourselves. From the earliest times of human settlement, *homo sapiens* has a long history of environmental degradation, over-exploitation of resources and disregard for landscapes (e.g., Hegmon et al., 2008). In some cases, loss of environmental resources prompted various responses from the ingenious invention of irrigation to migration of communities to spectacular failure. This legacy is not unique to any single settlement or culture, but is a universal characteristic of human nature. To acknowledge this feature of humans and their interactions with the environment from the outset is necessary for any critical evaluation of how we must proceed towards any future, whether for the next 40 or 400 or 4000 years. The critical difference between environmental circumstances 10,000 or even 2100 years ago, is the rapid explosion of human population and the acknowledgement that we have reached a limit where “patient Earth” has reached diminished capacity for absorbing human forcings without fierce retribution.

The symptoms or diagnostics for our malfunctioning biosphere are clear: diminishing resources, compromised air and water quality, alarming rates of biological extinction and declining biodiversity, and a climate system that is changing in response to hitherto unprecedented rates of change to the atmosphere. To a large extent, recent changes are well understood and are largely attributed to the human enterprise, including industrialization, massive changes in transportation infrastructures, deforestation, large-scale agricultural practices and their associated fertilization and irrigation practices. To a large extent, concern for a healthy Earth system has galvanized the scientific community to produce assessments such as the U.S. Synthesis and Assessment Products (SAP), (e.g., Backlund et al., 2008) where climate change is already affecting U.S. water resources, agriculture, land resources, and biodiversity. (e.g., Figure 1). Further, Backlund et al., (2008) state that these changes will continue to have significant
effects on these resources over the next few decades and beyond. At the global scale, the Millennium Ecosystem Assessment (2005) where the primary finding was that human actions are depleting Earth’s natural capital, putting such strain on the environment that the ability of the planet’s ecosystems to sustain future generations can no longer be taken for granted. At the same time, the assessment showed that with appropriate actions it is possible to reverse the degradation of many ecosystem services over the next 50 years, but the changes in policy and practice required are substantial and not currently underway. Additionally, the Fourth Assessment Report (AR4) of the Intergovernmental Panel for Climate Change (IPCC) where observations of increased global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level have confirmed that warming of the climate system is unequivocal (Figure 2). In addition, the AR4 confirmed that most of the observed increases in global average temperatures from the mid-20th century is very likely due to the observed increase in anthropogenic, or human, greenhouse gas (GHG) concentrations to the atmosphere Bernstein et al., 2007).

Results from international assessments, as those described above illustrate the gravity of the problem. Society has responded by partial solutions to specific problems without a systematic and careful consideration of impacts, or effectiveness with respect to an integrative approach to the innate coupling between human and environmental systems. Recognition of the inter-connectedness and endogenous relationship of humans to the environment requires new and innovated approaches for diagnosing and implementing solutions that are more integrative. From coral reefs, to fisheries, to forest management, to agriculture, rangeland, rural and urban environments, there is a cognizant recognition that the world is a diverse place, that one-stop shopping or simple solutions will not fit every unique problem. In addition, implementation today does not necessarily result in an instantaneous response by the Earth system. Inherent time lags exist from actual onset of a problem to the perception, or recognition through to diagnosis and prescription. Finally, it is becoming clear that the dynamics of human and environmental systems
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are not simply causative in nature, but rather, transformations of human settlements, whether they are marginal or spectacular are often the result of multiple, interacting factors that emerge from environmental (e.g., drought), socio-political (e.g., rigidity of social systems) and socio-ecological (e.g., denudation of resources). Lessons from the past can often provide insight into current diagnostics of such social and environmental interactions (e.g., Hegmon et al, 2008, 1998, van der Leeuw et al, 2005), but human histories and anthropological lessons must be tempered with an understanding that we cannot simply pack up our society and move to another planet. We are reaching our limits and must learn from those successful and innovative lessons from our past to develop multiple approaches and paths for a future.

As an example of planetary boundaries, air pollution has become a problem of global significance with important health consequences. The primary determinants of air pollution are the scale and composition of economic activity, population, the energy mix, the strength of local pollution regulation, and geographic and atmospheric conditions that affect pollutant dispersion in the atmosphere. Even though measures have been taken to limit emissions of primary pollutants in the industrialized regions of Europe and North America, the number of days exceeding the air quality standards in these regions remains excessive (Fig. 3). At the same time, economic growth in the developing countries world has created huge amounts of pollution in urbanized centers along with wealth. Air quality in cities of China, Africa and South America has worsened dramatically during the last decades (Figs. 4 and 5), with considerable impacts on health and, according to the World Health Organization, the premature death of nearly 1 million of people each year. Reduction in crop productivity and impacts on natural ecosystems are also considerable. The reliance of several countries on coal (an extremely dirty fuel source), the extensive shift towards diesel automobiles and insufficient environmental regulations are also to blame.
The earth is inhabited by millions of different kinds of creatures, each uniquely adapted to their local environment in order to acquire the energy, as well as the other vital resources, necessary to sustain their growth and reproductive capacity. Through reproduction the genetic information gained during the course of evolutionary processes is passed on to future generations. The struggle to obtain energy, water and nutrients is true of all life. It is the competition to capture these resources, wherever they might reside, that leads to the great diversity of life and the complex food chains that characterize it.

The assembly of species and their interactions with each other, and with the physical environment, constitute an ecosystem. These interactions result from the mining of resources by organisms from the environment. They do this by utilizing the energy captured directly from the sun or by consuming other organisms. Primary producers in terrestrial systems pull water and nutrients from the soil. The water moves through plants to the atmosphere unavoidably being lost from the plant due to the requirement for capture of CO2 from the atmosphere. These ecosystem processes, the capture, utilization and loss of energy and carbon, water and nutrients form the basis for the human life support system and the flows of water and nutrients represent the operation of biogeochemical cycles. In an analogy ecosystem processes can be considered a factory. As in any factory, there are many pieces, the species in our analogy, but these pieces are of different sizes and abundance and they perform different roles, again as in an ecosystem. The difference in an ecosystem is that the parts are self-replicating, and further, new species can enter into the system and alter the whole dynamics of the system by how they gather energy, water and nutrients.

The products of the functioning of ecosystems are essential to society, and its well being, and have been termed ecosystem services. These services include food and fiber, or provisioning services; regulating services, such as climate,
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disease, and flood control and pollination, and cultural services such as recreation, aesthetic beauty, and spiritual inspiration.

In 2005, a report, the Millennium Ecosystem Assessment, that was five years in the making, concluded that during a very brief period in history, the past 50 years, we have seen a dramatic reduction in the capacity of the earth’s biotic systems to deliver ecosystem services. We have degraded some 60% of nature’s ecosystem services, including water purification, disease and pest regulation, pollination, genetic resources, fisheries, and aesthetic values, to name but a few. These losses have accumulated as we have dismantled the base of the chain---we are seeing losses of diversity in all dimensions, from genetic diversity, species richness, population sizes, and ecosystems. With these losses, the delivery of the services of the “factory” goes with them. The rather sobering result of this study was that not only have there been large losses of important services but that most of the damage has been done in the past 50 years. More sobering yet is the prediction that these losses are accelerating and that the next 25 years most likely see losses as great as we have seen in the past 50 years.

The primary determinants of air pollution are the scale and composition of economic activity, population, the energy mix, the strength of local pollution regulation, and geographic and atmospheric conditions that affect pollutant dispersion in the atmosphere.

Because we are in an era of world of unprecedented rates of human induced environmental atmospheric change (e.g., Figure 6) with unknown rates of Earth system response The situation is, we are in a somewhat unstable, perhaps untenable situation characterized by a great degree of uncertainty. From times of early human settlement, the collapse, or failure of a society, as in the classic example of Easter Island, or cataclysmic environmental stress, such as drought-induced
crises (e.g., dust bowl of the 1930’s in North America) are indicators that we are in an unprecedented state of uncertainty. While there are examples of thoughtful action such as the American dust bowl resulted in soil conversation policies and statutes to mitigate erosion following the America dust bowl of the 1930s, and the Montreal protocol limiting the production and use of ozone depleting substances after the ozone hole was confirmed in the 1980s, discovery of an ozone hole prompted unprecedented international coordination through the Montreal Protocol, global consensus and policies have generally been slow and ineffective with regard to implementation of climate change policy (e.g., the Kyoto Protocol). In this chapter, we start with an idealistic vision of an aware and activist society that is sensitive and responsive to environmental change. This acknowledgement leads to the recognition that a new partnership between society and the environment is needed in order to consider a self-critical evaluation of possible pathways forward in this new partnership. Finally, we provide suggestions for a priority of governance and authority across scales with an emphasis and recognition of a ‘systems’ approach for a healthy world in 2050.

2. Changing the relationship between society and nature: a new integration of humans people with the natural in their environment

One way of looking at the current environmental crisis is as an imbalance in a coupled social and ecological system. Looking at the whole world as a complex adaptive system (refs Ostrom, Folke, Lenton & van Oijen and others), where the physical environment, nature, and human society are fundamentally interlinked, is proving a very useful conceptualisation. Ostrom and Folke (and others) describe this as a complex adaptive system. The complexity of the system arises from the intricate interplay among living organisms, including the human species, and their interactions with their physical “home”, the planet Earth. The complexity of the
system means that changes in one aspect often result in effects felt elsewhere. Human consciousness extends the normal conception of adaptive systems, where the current dynamics are simply shaped by the historic development of the system, to one where there may really be a capacity to learn from experience and select deliberately among potential future pathways.

One way of looking at current environmental problems is as an indicator of gross imbalance in this intrinsically coupled social and ecological system. It has become clear that the current pathways of consumption cannot be continued into the future: the natural system puts a constraint on the socio-economic subsystem. This constraint has been disregarded so far, partly because it is far from clear where the limits could and should lie. Limits get recognized only when one is inadvertently exceeded. In the past, such a lack of recognition of the limits has led to the collapse of some human communities, including whole civilizations at a significant regional scale (academic refs). The consequences of a change to this interconnected system – perhaps the loss of a single species, or the reduction of a key natural process below a threshold – could have knock-on impacts for our overall life support system. There is now a need for a new focus on identifying what might be the boundaries and safety margins in the human-nature relations. In the absence of this, human civilization could be putting itself at risk (where the precise cause and the magnitude of that risk may both be unknown).

The complexity of the system arises from the intricate interplay among living organisms, including the human species, and their interactions with their physical "home". It is characterised, too, by non-linearities, with various implications for society's responses to environmental degradation. First of all, the consequences of a change to the system – perhaps the loss of a single species, or the reduction of a key process below a threshold – has knock-on impacts for our overall life support system. The scale and manifestation of these impacts are not easily predictable (any better ref - more ecological – than the Lenton/Schellnhuber tipping points one?). Nevertheless, human society has apparently operated on the tacit assumption that incremental damage happens on a
The concept of limits tends only to be recognised when one is inadvertently exceeded. In the past, this has spelled the end of some human communities, including whole civilizations of a significant regional scale (Diamond, Ponting, other academic refs). There is now a need for a new focus on what might be the boundaries and safety margins, because human civilization at the global scale could be putting itself at risk.

There is no shortage of evidence that nature influences the working of human society, and that society shapes nature to its advantage. In other words, changes permeate the interconnected system. Human society has evidently exploited this throughout its existence – agriculture and technological change are adaptations that have extended the reach of human society across the world (also Hobbs et al 2006 – SCOPE ecosystems article).

There are still comparatively few conceptual tools to describe and explore this socio-ecological system as an integrated whole. In most cultures worldwide, academic divisions have fallen between the study of human society and the study of the physical and natural world. As a result of this divide, there is now a profound epistemological and ontological divergence – social scientists and natural scientists quite literally see the world differently and speak different languages. The incompleteness of expert knowledge about the interconnected nature-society system is a constraint on effective response, each having several more disciplines. The present situation requires new knowledge processes that will also ensure informed participatory decisions are needed. The development of discipline-based knowledge has happened over the last ~three hundred years, but there is arguably a need to accelerate the process of their reintegration for the generation of multidimensional, holistic knowledge now.

There are some examples of this conceptual integration. In the area of environmental policy, the DPSIR framework (OECD, 1986, etc) captures the iterative dynamic of human and environmental change; societal driving forces change the
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state of the environment, eventually impacting on the human societies that depend on a well-functioning natural environment to the point that they seek responses, which can involve direct remediation of the problem, mitigation of its effects, or more fundamental adaptive changes to society's priorities. With regard to environmental management, there is also well-tested operational experience – particularly in coastal zones and river basins, where environmental problems had become profoundly evident and the diversity of stakeholders (including flora and fauna - non-human ones stakeholders!) compelled more integrative dialogues.

This rebalancing of the interaction of our own species with the rest of nature will depend on is a reversal of a very widespread and long-standing detachment of humans from nature. Many cultures over centuries have internalised a belief that people should have dominion over nature (refs. Cronon?). Clearly, humans are anthropocentric. The new enlightenment about our part in nature is just beginning to emergeing in the scientific literature of modern science. In o Other scientific traditions, the human-nature relations have been seen in the form of interdependence, however, these traditions have very small scale of operations in today's world,
3. The state of the planet and biosphere anno in 2050

2050 is only slightly more than a generation away. Thus, even on a human - let alone a geological - time scale, this vision represents only a very small step into the future. Consequently, the vision presented here for 2050 cannot be considered as an ultimate goal for the state of the planet. Even if we today could eliminate all human perturbation of the Earth System, it would simply not be possible for various functions and processes within the System to come within desirable limits by the year 2050. Many of the processes of the natural world operate at long timescales. Emissions of sulphur (the major cause of the acute acid rain problem of the 20th century) were cut radically across Europe and North America through the 1970s in response to health and environmental concern, but in many regions, the recovery of the aquatic and land ecosystems only became evident two or three decades later. Long time lags exist for other pollutants, such as glaciers and polar icecaps accumulated over millennia, and they will take a long time to disappear. The circulation of the ocean, a complex process shaped by regional differences in water temperature and salinity, is a centuries-long process too. This has implications for the re-equilibration of the anthropogenic carbon dioxide between the atmosphere, land and ocean: past emissions from fossil fuel burning and land use change have already committed humanity to significant temperature change (e.g., Ramanathan and Feng, 2008. The greatest concern, obviously, arises from irreversible changes, such as losses in biodiversity – the destruction of populations, entire species and habitats.

Given these time lags in Earth System adjustment, if we reduced our emissions to zero today, atmospheric CO2 would not return to pre-industrial levels until well beyond 2050. I have results from scenarios for CO2e that assume reductions at 2020. I can check also for climate 'commitment' runs that show what the climate, or atmosphere would look like if we stopped emitting now.
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show what the climate, or atmosphere would look like if we stopped emitting now. Therefore, the state of the planet in 2050 must be seen as a “stepping stone” on the road towards a sustainable future. Using that as a starting point, it is possible to define the planetary conditions which are a prerequisite for enabling continued development of human societies.

3.1 Redundancy and Active Precaution

In 2050, governance and management principles have abandoned the optimization principles which prevailed in the 20th and beginning of the 21st century. It has become abundantly apparent, from both science and practice, that the closely interconnected human-nature relationships do not follow linear, predictable and controllable patterns. It was this assumption of linearity that formed the fundament for an optimization regime which dominated fifty years ago. We now recognize that social-ecological systems exhibit a high degree of non-linear behavior. This is true for all types of systems, from local ecosystems such as lakes and forests, to regional systems such as the monsoon and rainforest climate systems, and global systems, such as the atmosphere, cryosphere and stratosphere. Could Sarah’s non-linearity in social systems come in here?

Recognition by scientists of the non-linearity of all of these different types of systems began to emerge at the turn of the millennium. At that time, it was the World population was already anticipated that the World population of 2050 would reach 9 billion – an increase of 50% over the population level at that time. Numerous social leaders and scholars (we could refer to some books, maybe in a box...) argued persuasively that recognized that the Earth System could not be expected to simply absorb a 50% increase in the pressures being exerted by human societies upon it without crossing or more “thresholds” or “tipping points” [need a definition].

By 2025, these insights influenced governance and management of both social (including economic) and ecological systems. The resilience of a society
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depends on its ability to sustain redundancy and diversity in the face of a rapidly increasing frequency and amplitude of environmental shocks, as a result of the anthropogenic environmental change over the past 100 years. In order to minimize the risk of undesirable tipping points in the Earth System, strategies are in place by 2050 that enable humanity to avoid pushing critical environmental parameters too close to the danger zone where tipping points cannot be excluded.

Uncertainties of risks remain high but an active precautionary principle is now in place and operational. Instead of trying to predict the future, humanity is now making all efforts to minimize risks of undesirable trajectories for present and future generations. This is used by support humanity to stay on the safe side of planetary boundaries, i.e., hard-wired boundaries in the stratosphere, atmosphere, cryosphere, and biosphere, which, if crossed, may cause undesirable state changes. As a global strategy, this has resulted in an explicit effort in 2050 to assure a high degree of redundancy and diversity in the sub-systems of the Earth System, including terrestrial, aquatic and marine biodiversity; concentration of GHG in the atmosphere, and elementary cycles, etc…

3.2 Reduction of Human Intervention in Earth System Function

Thus, by 2050, political, economic and environmental decision making has, for several decades, been made with consideration of Earth System functions, i.e. by assessing the potential impact of human activities on freshwater resources and the global elemental cycling. Human activities influence very many global element cycles. However, the primary focus during the early decades of the 21st century was on reducing anthropogenic influence on the turnover of carbon, nitrogen and phosphorus.

Following the publication in 2007 of the IPCC 4th Assessment report, in which the expected implications of the human anthropogenically induced changes in the carbon cycle were dramatically described, considerable global focus was placed
upon reducing this human influence of the carbon cycle. The 2009 UN Conference on Climate Change focused on establishing a global agreement for the reduction of greenhouse gas emissions to the atmosphere. While the absolute goals for emission reduction achieved at that Conference were disappointing, the Conference did result in a global agreement which, subsequently, formed the political basis for far reaching global environmental management initiatives.

Very soon after 2009, it became clear that it was essential to reduce global CO2 emissions from the burning of fossil fuels to zero as quickly as possible. At that time, the CO2 concentration in the atmosphere was, on average, approx. 385 ppm. When the non-CO2 greenhouse gases were also considered, the CO2 “equivalent” concentration in the atmosphere was approx. 450 ppm. On the basis of research carried out in the early 21st Century, it was demonstrated that such high concentrations of greenhouse gases in the atmosphere increased the risk of crossing a critical threshold (tipping point) in Earth System function to unacceptable levels. It was, therefore, internationally agreed that concentrations of CO2 in the atmosphere must not be allowed to continue to increase AND that they must, ultimately, be reduced to levels even below those of the early 21st Century.

This realization made it imperative that CO2 emissions from fossil fuels became zero as quickly as possible. This conclusion was strongly reinforced as initiatives designed to improve air quality, especially in larger cities, came into effect. These initiatives focused on the removal of particles created through combustion. The rationale for their removal was that the particles provided a health risk for the cities’ inhabitants. Ironically, however, it was demonstrated at about the same time as the 2009 UN Climate Conference that the combined cooling effect of these particles in the atmosphere was of about the same order of magnitude as the emission of non-CO2 greenhouse gases to the atmosphere. (possible FIG??).

Removal of these particles, then, greatly exacerbated the problem of global warming due to the anthropogenic introduction of greenhouse gases to the atmosphere and it
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was politically recognized that efforts to reduce emissions had to be stepped up. Control of emissions of non-CO2 greenhouse gases (i.e. methane, ozone, nitrous oxide) is exceedingly difficult for a number of reasons but, most importantly, because many of these emissions are related to global food production/security. Therefore, in order to keep global warming in check, it was internationally agreed to reduce CO2 emissions from fossil fuels to zero by 2050 by transforming the world's energy systems so that renewable sources of energy and energy conservation play a dominant role.  

This most important change in energy supplies that has allowed this goal to be achieved has been a massive increase in reliance on renewable energy forms, with solar energy being the most important of these. That solar energy now fills a much greater proportion of the global renewable energy portfolio than it did at the beginning of the century is the result of concerted research efforts to improve the efficiency of solar energy utilization. As the sun delivers to the Earth every year approximately 120,000 TW of energy and the current energy demand by human societies is only on the order of 15 TW, there is no reason to believe that access to energy will, ultimately, limit the development of human societies. Consequently, the campaigns to “save energy” that were so common in the late 20th and early 21st centuries have, literally, become of only historical interest.

It took some years, however, before solar energy became readily available at competitive prices and, in that period, tremendous advances were made in terms of using energy efficiently. Perhaps the most important of these was the development of “smart” systems in all units using energy (buildings, cars, etc). These “smart” systems removed the need for each individual to choose the behavior pattern that he/she considered to be most advantageous in terms of the effective use of energy. Computerised systems were developed to optimize energy use and these were, for example, able to reduce energy demands from large office buildings by up to 70%. [could have a box with some of these ideas but let’s see what energy comes up with]. While it is no longer necessary to conserve energy in the same manner that it was in...
In addition to reducing emission of CO2 from fossil fuel combustion, effective methods are now available to actively capture CO2 from the atmosphere and store it in a stable form. (Cartoon demonstrating such a system?) Demonstration plants have been established for this purpose and negotiations are underway aimed at ensuring an annual capture of CO2 from the atmosphere equalling the greenhouse gas effect arising from the global anthropogenic release of non-CO2 greenhouse gases. By essentially eliminating all anthropogenic influence on greenhouse gas accumulation in the atmosphere in this manner, it is predicted that atmospheric greenhouse gas concentrations will – in the centuries to come – eventually stabilize at pre-21st Century levels.

3.3 Guardians of the Earth System

In parallel with efforts to curb GHG emissions, the first half of the 21st Century saw political and public focus on safeguarding of the capacity of elements of the Earth System to continue to function as carbon sinks/sources. Here, in 2050, new governance structures at the global level are in place. These structures recognize that a prerequisite for a sustainable future for the Earth System is that human societies accept that they have a responsibility to perform as “Guardians of the global element cycle”. This responsibility includes having distributed Earth observatories, and mechanisms and assessment abilities to enforce international agreements on the distributed sink commitment among the nations of the world. Looking back, it was with shock, that the citizens of the world recognized, in the early 21st century, the massive global free ecosystem services that nature had
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Provided humanity freely with in the wake of the industrial revolution.

Approximately half of all human emissions of GHG were estimated to have been absorbed by oceans and land and, in the early 21st century, increasing evidence was presented suggesting that there was a dramatic risk of a decline of this capacity. "Let nature do its job" was the slogan of a growing global awareness campaign, which rapidly entered the center stage of global environmental governance. The fear of non-linear feedback effects, where warming triggered by human emissions, set uncontrolled released of stored carbon and methane in the oceans and land systems, grew rapidly. By the early 2010s, it was clear that no country in the world was willing to take the risk of transgressing thresholds where massive release of GHG to the atmosphere from the Earth, itself, would occur. Science pointed at the risk that it could no longer be excluded that such a threshold was transgressed already in the late 20th century, leading to pointed the way for the major investments in strategies to "suck b CO2 from the atmosphere".

Here in 2050, the oceans have received far more recognition in are the centre stage of global environment governance, as they hold the key to long-term global warming (as a result of the inertia in the warming process) and the key to large part of the
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Carbon sequestration capacity. The acidification trend of the 20th and early 21st century has been reversed thanks to the reduction in CO2 emissions from fossil fuel combustion. The pH levels in the world’s oceans have now stabilized at levels required to avoid the risk of losing the ability of ocean species to absorb CO2.

By 2050, the air of the cities of the world should be of high quality. Although air pollution has become a global problem, hot spots are associated with urbanization/industrialization and wildfires. The reduction in air pollution requires immediately a drastic reduction in the emission primary pollutants. Historically, emissions reduction strategies have focused on just a few pollutants (ozone precursors including CO, VOCs, and NO) as well as particle matter PM-10. There is a need, however, to consider other pollutants including fine particles (PM-2.5 and even PM-1), which penetrate deep in lungs, as well as PM precursors, such as sulfur dioxide (a product of coal burning) and ammonia (a product of cattle). In addition, the release of methane (another ozone precursor and a greenhouse gas) and of nitrous oxide (a greenhouse gas linked to the use of nitrogen fertilizers) will have to be limited. A fast action is to reduce the release of soot particles in the atmosphere by limiting the use of diesel cars as well as the frequency of biomass burning events. The strategy to reduce emissions may be different according to the regions of the world, but they all require a limitation in fossil fuel production, changes in our mode of transportation, and the development of new agricultural practices. The limitation of savanna fires and the limitation in domestic burning, specifically in the tropics should be another objective.

The problem of air quality cannot be considered independently of other issues such as climate forcing, or the health of ecosystems. A cleaner atmosphere, with reduced concentration of aerosol concentrations will rapidly enhance the Earth’s mean temperature. A warmer climate will also modify the emissions of biogenic gases including precursors of ozone. High concentrations of ozone affect the health of ecosystems and therefore the ability of oxidants to be deposited at the surface. As
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shown by Figure 7, the problem of air quality cannot be treated in isolation, but is intrinsically linked to the climate problem, the state of the biosphere and changes and the water system.

On land, the few remaining rainforests, in the Amazon, the Congo, and in SE Asia, have been preserved as "global lungs and sinks". Forest systems world-wide are managed in order to increase their capacity to perform as global carbon sinks. Terrestrial ecosystems are maintained for biodiversity and as continued carbon sinks. The world's crop land has stabilized at around 15% of the land areas on the Planet, in order to safeguard carbon sequestration and biodiversity of the world's terrestrial ecosystems. Furthermore, agricultural systems on the Planet now have switched from being a source to being a global sink at a level of 1-2 Gt C/year.

3.4 Guardians of the global cycles of nutrients and water

The self-regulating character of the Earth System hinges on the functioning of the ocean and land systems, the elementary fluxes (e.g., methane, ozone) and the global cycles of nitrogen, phosphorus and water. In 2050, humanity has been able to reduce the manipulations of the N, P and water cycles to a level where they do not undermine sustainability of the planet, while still allowing the potential for human well being for all citizens on the Planet.

Humanity, already in the early 21st century, had added more nitrogen into the biosphere than the total natural biologically mediated uptake occurring on land. The result of this massive anthropogenic manipulation – primarily as a result of the industrial N fixation from the atmosphere to produce commercial fertilizers for agriculture – was vast environmental problems ranging from eutrophication of lakes and marine environments, loss of ecological resilience in the Earth's coral reef systems, and acceleration of N2O emissions resulting in accelerated global warming.
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Human activities also caused escalated global flows of phosphorus – from the Earth’s crust, through societies and into the oceans. Together, changes in these two major global nutrient cycles pushed terrestrial, aquatic and marine ecosystems, to the brink of collapse across the globe. This had multiple negative consequences for the ability of human societies to sustain and improve human well being across the globe. First, it eroded the capacity of ecosystems to provide humans with ecosystem goods and services – such as food and a healthy environment. Secondly, it eroded the long-term capacity of the biosphere to function as a sink of carbon. Thirdly, it increased emissions of N2O to the atmosphere.

In 2050, the challenge of balancing the use of freshwater for humans and nature was accomplished, as a result of the introduction in the early 21st century of an integrated land and water governance and management approach that incorporated the role of water to sustain both terrestrial and aquatic ecosystem functions and services. Now, on the whole, freshwater resources are safeguarded to provide direct human well being (water for food, energy, fiber, and timber), as well as water for terrestrial and aquatic ecosystems functions, goods and services.

This approach, including both green and blue water resources, enabled a strategic move towards safeguarding freshwater for carbon sinks, biological diversity, food, industry and domestic water supply. The challenges in 2050 remain tremendous. With a world population of 9 billion people, and the successful achievement of the UN Millennium Development Goals (the complete eradication of malnourishment, which amounted to 1 billion people in 2008), the global freshwater use for food production on the planet has increased by a staggering 3000 km3/yr in 2050, up from approximately 7000 km3/yr in the wake of the 21st century. However, this is seen as a major global success, as all predictions in the late 20th century, pointed at an increase of at least twice this magnitude. Dramatic, given that food production was and remains the world’s largest freshwater consuming human activity. This success was achieved as a result of a sustainable green revolution in tropical regions of the world between 2010-2020, which involved major improvements in water
Group IV: Environment, climate change, air and water pollution, health productivity, and introduction of sustainable land, water, plant management practices. Moreover, the freshwater challenge focused on upgrading rain-fed agriculture without which the accelerated global trend of drying rivers – from withdrawals of runoff for irrigation – would not have been reversed.

Supply of clean water for all inhabitants on the Planet was accomplished in the mid 2030s. This was a major management challenge and, actually, not a water resource constraint issue, which made it relatively easy to accomplish. A fundamental breakthrough, which enabled this achievement to occur so rapidly, was the rapid abandonment of the water polluting sanitation systems that had been established during the Industrial revolution in the 18th century, and which still prevailed in the early 21st century. Fortunately, these were decisively phased out in the decades that followed. In their place, sustainable sanitation practices – from dry sanitation to recycling of nutrients in water borne sanitation systems - were introduced. These enabled a major improvement in human health on the global level and a reduction of leaching of N and P.

**LINK TO WATER CHAPTER**

- My advice would be to try and incorporate Sarah’s into ours (I identified where above). If we mean (and I do) that humans are part of the Earth System (by the way, we talked about a definition coming in – is that in the intro?), then it seems artificial to take the ES first and then human societies.

We could then go directly to addressing the pathways and that could be done quite simply by, when we finish the chapter here asking the question:

**How did the world get to it in 2050?**

**4. Pathways to 2050**
What happens to the environment between now and 2050 depends very much on the decisions we take over that period as individuals, in our communities, nations and at the global level. While we cannot predict what these decisions will be, we can identify a number of dimensions for scoping them out. By combining various combinations of these dimensions we can delineate alternative pathways to the future. Such is the purpose of this section.

We have identified eight dimensions that are useful for describing alternative pathways that individual countries may choose to follow. This does not preclude international cooperation, which for dealing with problems such as climate change and ocean acidification is essential. Rather it helps distinguish among countries that may choose to approach environmental problems by emphasizing local and national initiatives rather than regional or global ones.

After defining the dimensions we show how they can be combined to describe the pathways that countries today are on. These were adopted largely in response to the more local and national environmental agendas of the 20th century. In comparison, the environmental challenges of the 21st century are more regional and global. They will require changes in a variety of dimensions if we are to move to pathways likely to be more effective in the future.

The dimensions we consider are:

**Development:** Currently countries may be described as less developed or developed using a metric such as the UN's Human Development Index. Their circumstances are likely to affect their vulnerability to environmental threats and their scope of action.

**Spatial:** Countries differ in their preferences for acting locally and nationally rather than regionally and globally.
Initiative: In some countries, action to address environmental problems is largely bottom up with great reliance on actions taken by individuals and/or environmental NGOs. In others, initiatives are more top down with government taking leadership.

Compliance: There is an extensive range of policy measures that can be used to secure compliance with environmental targets. These include voluntary actions with and without sanctions of some sort, information and education programs, tax incentives and penalties, trading schemes, and regulations of varying levels of prescription. These measures are not mutually exclusive but where emphasis is placed distinguishes different pathways.

Institutions: All countries start from an institutional structure inherited from the past. Some may choose to rely on these structures while others may experiment with something new. For example, as the world becomes increasingly urbanized city governments may be given more powers. There may be increased or decreased opportunities for public participation in environmental decision making. Countries may support an enhanced role for international organizations.

Investment: Responding to environmental problems will require a considerable amount of new investment. Countries differ in the extent to which they will rely on these investments to be undertaken by the private and public sectors. Other organizational structures such as co-operatives or community trusts may also contribute to investments. Differences in investment in education and training are also very significant and will have to be addressed in future pathways.

Technology: For many environmental problems the technologies necessary to deal with them are already available. Others may require new technologies. Different pathways can be described by the extent to which countries take
action to stimulate the adoption of existing technologies rather than count on the development of new technologies which may be more effective and possibly cheaper.

Growth: Technology is about efficiency, i.e. doing more with less. In the case of environment this means doing more with less environmental impact. But if the scale of an activity grows faster than improvements in efficiency then the net result is an increase in environmental impact rather than a reduction. This has been realized in countries which have taken measures to reduce the rate of growth in population. Now, as the 21st century unfolds, we expect to see economic growth given much less priority than in previous times, especially by countries that have already attained a high material standard of living.

Figure 1 includes each of these dimensions on a single diagram that we use in figure 2 to characterize the pathways that 4 countries are currently on. We expect that each of them will have to make changes to these pathways if they and the world at large are to adjust to the Earth system biophysical constraints that are increasingly in evidence.
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Figure 1: Identifying Pathways to the Future
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Figure 2 – Current Pathways
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Future Pathways

These diagrams describe broadly the pathways of five countries as we see them today. They reveal some major differences in the way that these countries have responded to environmental problems in the past and, unless changes are made, will attempt to deal with the problems confronting them now. As already noted, the environmental problems of the 21st century are and will be more regional and global in nature. We therefore expect changes in the pathways these and other countries choose to follow to achieve environmental targets over the next 40 years or so. Of course, countries may embark on one pathway today and modify it in the future. Indeed, this is likely to happen. Furthermore, there is no single pathway that is best for all countries and it is not possible without considerable additional effort to determine which future pathways are more likely to succeed than others. Nonetheless, we surmise that for some dimensions at least there are more and less effective approaches which can be identified.

First of all, we think that international cooperation will become increasingly important. Countries which have traditionally focused their efforts on national and local environmental problems, or have allowed concerns for national sovereignty to impede effective international agreements and the strengthening of international institutions will have to move away from that position to one more in keeping with the global character of environmental impacts.

Related to change at the international level is the need for new institutions at other levels. While some progress has been made in dealing with environmental problems with a comparatively limited geographic scope, we do not think that countries have institutions in place with sufficient support that are adequate for generating and utilizing all the required scientific and technical information. This is especially so given the context of risk.
uncertainty and irreversibility within which many decisions must be made. Nor do we think that, generally speaking, there is adequate provision for public participation in decisions that affect the environment. This is one of the reasons for the disproportionate impact of environmental threats to poor and disadvantaged people.

No doubt, the development and implementation of new and improved technologies will play an important role. Some of these will come from the private sector, others from the public sector with the balance varying from country to country. The consequent gains in efficiency are in danger of being over-ridden by the increasing scale of economies as has happened in the past when improvements in energy efficiency led to an increase in total energy use. We expect the pursuit of economic growth, especially in rich countries to be questioned much as population growth has been since the mid 20th century.

The variety of pathways to the future offer the possibility of success but no guarantee. However, we conclude with the hope that a broader appreciation of the alternatives will help.

5. Final Reflection

The human species has advanced at a dizzying pace through the rapid evolution of the brain and its mind, leading to advanced powers of cognition, problem-solving and adaptation. It is this phenomenal development that has both got us into this mess, but can also get us out of it. Two fundamental characteristics of human behaviour are communication and memory, which together allow us to remember, respond to, and learn from past events.

The global village that we now inhabit is bursting at the seams, and unlike isolated cultures which in the past may have imploded, our societal response must now be global. Many of the necessary advances in human society, whether technological or
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behavioural, are without precedent. Global consciousness, international equity, enlightened and restrained lifestyles, and non-monetary drivers of development present new, exciting, unchartered waters.

In contrast, envisioning a positive environmental paradigm for 2050 need not be without precedent. Planet Earth has long known environments that function naturally, through biogeophysical cycles that successfully balance the books, and has even experienced human societies where resource use did not exceed the pace that natural processes could respond, replenish, and recover.

Our challenge is to engage the very cognitive processes that have got us where we are today. We need to develop memory, not just on the emotional timescale of a human lifetime, but through historic records, archaeology and anthropology we must learn to “think back” over our species' lifetime. Furthermore, using emerging scientific methods, including dendrochronology (tree, coral, ice), ice-core isotopic measurements, molecular records and paleoclimate reconstruction and geology, we must “remember” further back, to include rare, gradual, and recurring climatic events.

Through this approach, we can build a vision of the future which is informed by past events, and “look back to look forward” to a safer future. If we stick within the emotions of the memory of a human lifetime, we risk sliding towards irreversible degradation through an ever lowering expectation of a planet in balance. The intergenerational shifting of the baselines which define our targets, reducing the ambition of environmental recovery to restoring habitats to those we ‘enjoyed’ as children, will otherwise lead to disaster.
6. Conclusions

We currently are in a state of increasing environmental crises

Science and technology are in a period of rapid advancements

Risk-adverse and/or risk decisions made by those not vulnerable

Governance structures are not adequate to address the environmental challenges that we face.

A vision for Planet 2050 with recognition of unforseen advances:

It is common knowledge that Earth system resources are finite. This recognition puts constraints on socio-economic, -ecological, -political (and associated sub-systems) on environmental management, policies and approaches.

Environmental approaches are based on integrative risk trajectories that societies are willing to take, not on simple predictions of the future.

The role of nature as a life support system is a key component in all decision making

All citizens of the planet are equipped with knowledge to act responsibly to integrative environmental challenges
Governance decisions are consistent with local to global issues and challenges

There are a variety of potential pathways, to solve local to global environmental challenges. There is no one unique solution, the shortest distance between two points is not necessarily the correct path, but rather, the possible trajectories and pathways are the goals, not the goal itself.
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**Literature Cited**


Figure 1. Ponderosa pine after the Hayman fire in Colorado, June 2002. While no one fire can be related to climate or changes in climate, research shows that the size and number of Western forest fires has increased substantially since 1985, and that these increases were linked with earlier spring snowmelt and higher spring and summer air temperature. Photo courtesy USDA Forest Service from Backlund et al., 2008.
Figure 2. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). Figure from Bernstein et al., (2007).
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Figure 3

Figure 4
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Figure 5
Figure 6. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. Figure from IPCC (2007).
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Figure 7
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