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Resilience and Sustainable Development 2.0

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Photo of Stockholm Resilience Centre, Albano, Stockholm.

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1 Introduction

1.1 Purpose and scope

The agenda for sustainable development has changed fundamentally over the past decade. The globalization of environmental processes and impacts, with anthropogenic climate change as the most prominently recognized issue, has forged a deeper understanding that societies in the world are not only interconnected through social and economic systems, but also through the biophysical life support systems of planet Earth.

Today we recognize that driving a fossil fueled car in Stockholm impacts on the long-term fish catches of Inuit communities on Greenland and the rainy seasons of small-scale farmers in Tanzania. The UN Millennium Ecosystem Assessment, the first global "health control" of the world's ecosystems, in 2005 showed not only that humanity is degrading the living natural capital assets more rapidly than ever before, but also that ecosystem functions and services form the fundamental basis for human wellbeing. Ecosystems provide a number of services from local to global levels, such as food production, fibre, genetic resources, pollination, regulation and supply of freshwater, climate regulation and amelioration, and natural hazard protection. In short, Earth's ecological life-support systems form the basis for social and economic development (see fig 1), and development decisions in one corner of the planet often affect the well-being of people across the planet.

The ruling "command and control" paradigm in dealing with natural resources and environmental issues, where humans are seen as being apart from and not a part of nature, has resulted in accelerated decline in the ability of the biosphere and its ecological systems to sustain and enhance human wellbeing. In contrast to this one-directional view, the perspective presented here is very much bi-directional. While human actions in a globalised world shape the processes of the biosphere across the whole planet, the feedback effects of the changing biosphere on humanity fundamentally determine the course of our own development. Hence, the environment agenda has become a sustainable development agenda.

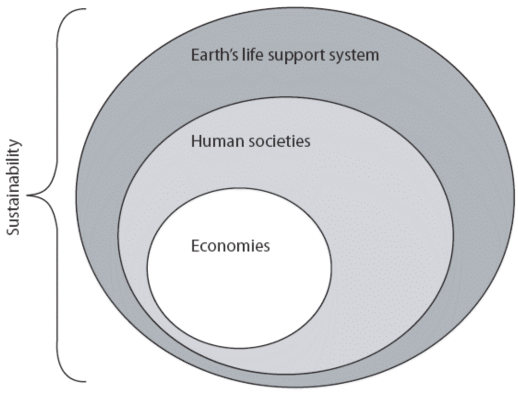


Figure 1. Earth's life-support system forms the basis for social and economic development.

Controlling production factors in the environment that produce one (generally marketable) outcome – such as a specific fish species or food crop – has in the short term resulted in remarkable increases in productivity (fish catches, agricultural yields) often in large and climate vulnerable monocultures. However, the longer term effect, due to loss of broader diversity in

landscapes, generates increased likelihoods of tipping points in ecosystems (Folke et al. 2004) with severe socio-economic consequences.

> ***"Resilience is the answer to the question: how can things change and persist at the same time?"***
>
> Steve Carpenter, Professor of Zoology at the University of Wisconsin-Madison

This pathology of current natural resource management (Holling and Meffe, 1996) combined with the current paradigm of environmentally independent economic growth has resulted in a number of major negative externalities. Human induced climate change is the most well-known of these, and has even been labeled "the biggest market failure the world has ever seen", according to the Stern Review on the Economics of Climate Change (2007). The resilience of the Planet has so far camouflaged half of the human emissions of greenhouse gases, by sequestering carbon emissions in oceans and land systems. Probably, this is the world's largest "free" ecosystem service.

Recent estimates of the EU project The Economics of Ecosystems and Biodiversity (TEEB, 2008) suggest that deforestation alone has caused larger economic losses than the current financial crisis (losses of 2-5 trillion USD, as compared to 1-1.5 trillion USD in the USA as per October 2008). While the financial crisis has caused social feedbacks at a massive scale, these are rapid feedbacks (with the dramatic fall of investment banks, stock markets, jobs and purchasing power among consumers). The slower environmental feedbacks are still in the pipeline, with potential large-scale tipping points down the line (Lenton et al. 2008), and it is such feedbacks that need to be redirected in collaboration with economic development to steer human actions and wellbeing into sustainable pathways.

Resilience thinking provides a basis for understanding and developing strategies for sustainable transformation in turbulent times. Resilience – the ability to deal with change, often sudden and surprising, to move on and continue to develop – can help turn crises into opportunities.

Humanity has entered a new self-induced geological era, *the Anthropocene*, where the sheer pressure on the Planet's life-support systems from a rapidly growing world economy and population means that humans today are the dominant driving force of the Planet's dynamics (Crutzen et al. 2000). The issue at stake is broader than climatic change. It is about a whole spectrum of global environmental changes and the challenge of humanity to navigate the future as active stewards, not for the sake of the planet but for the sake of our own development. An example of multiple-interacting drivers of change and possible outcomes is provided in Figure 2.

Despite growing evidence that surprise, abrupt change, thresholds and regime shifts constitute normality in ecosystems, we still govern and manage forests, water resources, agricultural land and other natural resources, as if they follow linear, predictable, controllable pathways in an incremental way. Now we know better. Long periods of slow change are generally followed by periods of abrupt change, under the pressure from multiple drivers. We see proof of this everywhere. The recent scientific surprise of the sudden acceleration in Arctic ice melting, which has made the Arctic summer almost ice free at least 5 decades earlier than the worst-case scenarios projected, is one recent example. The reason is a (not well understood) complex interplay between several slow variables (ocean temperature, darkness of the land surface, and climate variability). The sudden loss of 50 years forest investments in southern Sweden after the storm Gudrun in January 2005 is another example, where loss of resilience, during decades of

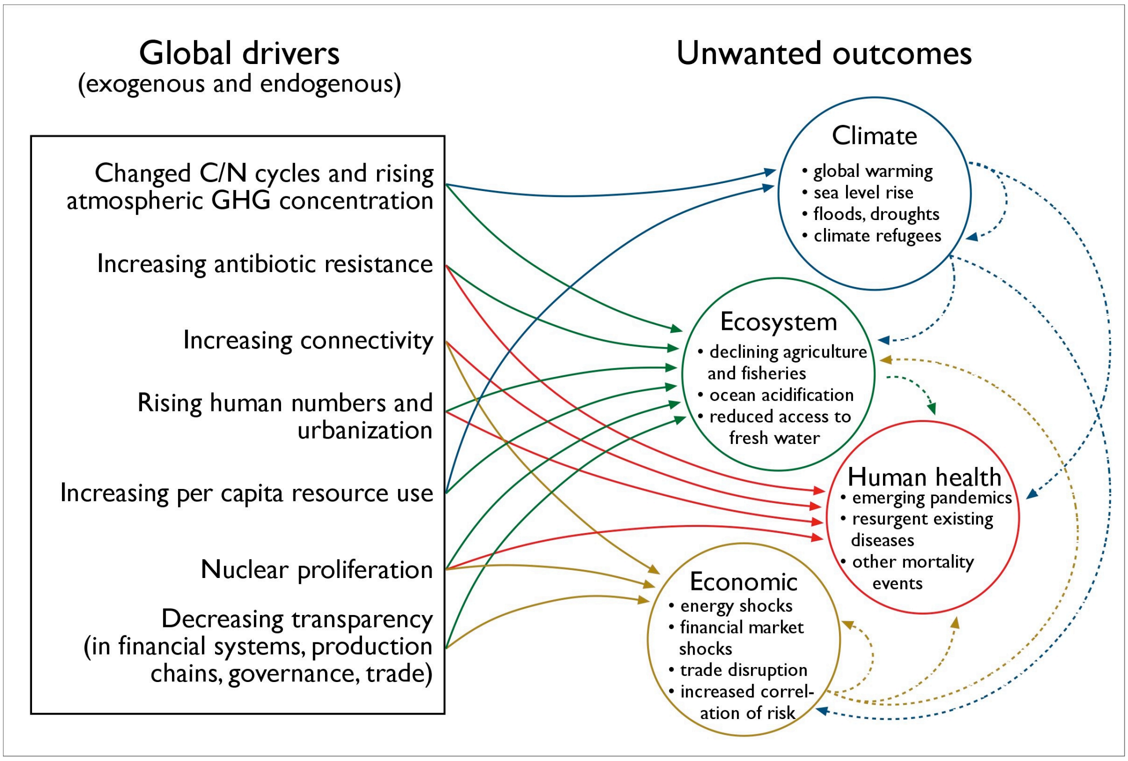


Figure 2. Examples of interactive effects of global drivers on the state of the world (from Walker et al. in prep). C = carbon, N = nitrogen, GHG = Green House Gases.

monoculture-oriented forest policy, resulted in severe consequences for those involved from the trigger of a freak storm occurring under warm and moist conditions. Similarly, the hurricane Katrina in the US – a predictable event striking a social-ecological system that had undergone decades of resilience loss – pushed a whole society from a desired to an under-desired state, generating a social disaster with massive economic costs and human suffering. Yet another example is the seven years of consecutive drought in Australia, which pushed the awareness of a society across a social tipping point, making the first government on Earth fall on the climate change issue. Consequently, the first action of the new government under Prime Minister Rudd was to sign the Kyoto Protocol. All these examples, illustrate failures to manage resilience in order to stay in desirable states of development in periods of turbulence. They also illustrate that resilience is not a good thing in itself. Sometimes resilience needs to be diminished in order to transform to improved situations (see further below) and in other cases it needs to be strengthened to avoid shifts into unpleasant situations (like a new global climate regime)

Humanity is now in a state of high turbulence as a result of both social and environmental changes and challenges. The future for ecological and climatic challenges is that they are most likely to increase, generating even larger turbulence.

The resilience lens provides a framework, complementing the broader sustainable development agenda, to meet these growing challenges.

This lens, or 'resilience thinking', has evolved over the past 30 years (e.g. Holling, 1973) from the insights that (i) the biosphere (the world's ecosystems) constitutes the basis for social and economic development, (ii) societies constitute interlinked social-ecological systems, which (iii) are characterized by a dynamic interplay between periods of slow and rapid change, and (iv) with cross-scale often complex interdependencies from the local community to the planetary scale.

These insights are not based on theory, but on actual observations of how the world works. Resilience describes the capacity of a system, e.g., a community, society or ecosystem, to withstand shocks and still continue to function in a desired way. It covers three key features: *persistence*, *adaptability* and *transformability* (these are further elaborated in section 3).

Resilience thinking and practice is increasingly tested and applied across policy sectors (Table 1). The common theme in all these research activities and applications is the realization that the resilience of a system hinges on investing in social and ecological diversity, flexibility, learning, and the ability of institutions to be active stewards of the slow underlying variables that will determine the ability to withstand undesirable change and continue to develop.

Resilience provides a missing link of sustainable development. It is not a substitute for sustainable development, but a necessary component. It needs to be made clear that while sustainable development, per definition, is always perceived as something positive, resilience (particularly the ability to persist in a stable state) can be both positive and negative (dictatorial regimes in the world have in many cases proven to be very "resilient"). Hence, sometimes the first step towards sustainable development is to reduce undesired resilience, in order to allow for transformation into a new alternate and improved state.

This document complements the report "Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations", which was produced for the World Summit on Sustainable Development (WSSD) in Johannesburg 2002, and commissioned by the Environmental Advisory Council of the Swedish Government (Folke et al., 2002). Here, we present recent advances in the understanding of the role of resilience for sustainability, from local to global scales. It emphasizes the concepts of social and ecological resilience, advancements in resilience thinking (particularly related to the risk of abrupt changes and transformations) and the opportunities from applying resilience thinking in governance and management. We do not know exactly what governing and managing for resilience will mean in practice across all policy sectors. We do, however, know enough to start experimenting with a broader, resilience based approach to sustainable development. The need is clear. The old "optimization" paradigm is unable to deal with the challenges facing humanity; in fact it contributed to them. Incremental change is no longer an option as we know that institutions, governance and practice currently evolve more slowly towards solving the huge challenges facing humanity than the global environmental changes themselves unfold. The implications are major and multiple.

Table 1: Examples of resilience thinking being applied in different policy sectors.

Policy Sector	Applications of resilience thinking	Institutional reference
Finance/economics	Inclusive wealth analyses in national accounts Discounting "Fat-tail risks" and threshold effects Economic value of functional diversity and ecosystem services	Research analyses (e.g. Dasgupta and Mäler, 2000) Research analyses (Weizmann, Frank Ackerman, etc…) European Environment Agency assessment (TEEB, 2008)
Agriculture	Water for food and development	The 2nd phase of the Challenge Programme on Water for Food, a research program of the CGIAR
Fisheries	Resilience and Ecosystem-based management	ICES working groups, EU Green book. Great Barrier Reef governance

Environment	Mapping of ecosystems for human wellbeing The risk of a flip of the Baltic Sea Mapping of Ecosystem services in Strategic Environment Assessments Plans for an equivalent to IPCC on biological diversity and ecosystem services Threshold effects in the climate system due to slow feedbacks from the biosphere	UN Millennium Ecosystem Assessment (2005) Swedish National Environment Advisory Council (2005) DAC Network OECD (Sept 2008) UNEP proposal of an Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Influence on the UN climate negotiations (e.g., www.350.org)
Industry	Growing strategic interest among industries to understand the existence of multiple stable states in social-ecological systems that constitute their local, regional and global markets and the risk of crossing critical, abrupt and undesirable tipping points due to global environmental change Industrial ecology (from linear systems to a closed loop system; wastes become inputs for new processes).	e.g., dialogues with the World Business Council for Sustainable Development (WBCSD) on global scenarios and informal dialogues with companies such as IBM, Ericsson, Volvo, and Scania. http://www.umich.edu/~nppcpub/resources/compendia/INDEpdfs/INDEintro.pdf
Transport	New Zealand Energy Strategy to 2050: “Increasing the diversity of transport fuels through introduction of biofuels and electric cars will also make New Zealand more resilient to international oil price uncertainty and risks of supply disruptions”	“Resilient, Low Carbon Transport” (Draft New Zealand Energy Strategy to 2050): http://www.med.govt.nz/templates/MultipageDocumentPage____25253.aspx
Foreign Affairs Security	Dialogue on how resilience thinking can contribute to strengthen failed/weak states	Austrian government dialogue (with IIASA) Tadjikistan and other regions (with Resilience Alliance)
Foreign Affairs Development	Sustainable recovery after the tsunami – using social-ecological resilience as a basis for rebuilding coastal livelihoods Building social-ecological resilience to climate change – a strategy for climate adaptation World Resources Report 2008 – “Roots of resilience”	Sri Lanka fishery communities (Sida supported work, coordinated by SEI) Input to the Swedish Commission on Climate and Development (Stockholm Resilience Centre, 2008) World Resources Institute, Washington DC. 2008
Cross-sectoral	Australian Round-table on ”how resilient is Australia?”	How Resilient is Australia ?”, Australia 21 Discussion Paper, February 2008. http://www.australia21.org.au/pdf/Resilient08.pdf

1.2 Why the current approach has failed

Throughout human history, people have interacted with and shaped ecosystems for social and economic development (e.g. Redman 1999, Diamond 2005). During the last 50 years, however, human progress and action have altered ecosystems, biogeochemical processes (like carbon and nitrogen flows) and freshwater cycles from local to global scales, more rapidly and extensively than at any comparable period of human history (Steffen et al. 2004, Foley et al. 2005, MA 2005). The phenomenal expansion of the human dimension, made possible through the use of fossil energy, social and technological innovations, economic progress and democratic societies, has resulted in a globally interconnected system, not only in the social and economic dimension, but also in the ecological (see picture and text in figure 9 on shrimp farming, section 4.4).

Globalization is a major achievement, with numerous benefits like conflict resolution, peace preservation, knowledge sharing, access to new markets and diverse cultures. At the same time the tremendous improvements in technological, economic and material well being, in parts of the world, along with the widespread urbanization trend (>50% of the human population in urban areas as of 2006) have increased the gap between the life-supporting environment and human perception of essential sources for wellbeing. Within a few generations a large proportion of our own species, *Homo sapiens* (the intelligent monkey), has developed a belief system or a cultural world view of separation from the biosphere. It is as if the value of nature is simply a matter of our own preferences and that we are in control.

This mental alienation is reflected in many policies, practices, behaviours, technological developments and measures of progress that treat Earth processes as external to economic and social development, and fail to encompass the complexity and non-linear behaviour of natural resources and ecosystems (see sections 2.3-2.6). These include current indicators of agricultural production that measure progress only in terms of enhanced yields; in fisheries that focus on maximum sustainable yields of single fish stocks; in the timber focus of forestry; in the mitigation focus of climate change; in current measures of economic welfare; and even in the UN Millennium Development Goals, where the environment enters as one among many sectors. Such measures are at best partial, but at worst misleading in guiding societal development towards increased human well-being and sustainability. All in all, Walker (2005) concludes that most of the unwelcome surprises in natural-resource use systems stem from a failure of the ruling command-and-control management paradigm underlain by four flawed assumptions:

i) a focus on average conditions and particular time and space scales;
ii) a belief that problems from different sectors in these systems don't interact;
iii) an expectation that change will be incremental and linear, and
iv) an assumption that keeping the system in some particular state will maximise the flow of goods, indefinitely.

On the contrary, natural resource and environmental management must be seen as something else than merely about harvesting resources or halting pollution; it should rather be considered as stewardship of the very foundation of a prosperous social and economic development, particularly under conditions of rapid and directional social-ecological change (Chapin et al. 2009). It is in this context that the "resilience lens" (see section 3.1), or "resilience thinking" (Walker and Salt, 2006), becomes of great significance. As will be shown in this report, the resilience of many ecological systems has been eroded in everything from the Arctic to the tropical rainforests as a consequence of human actions. During the great acceleration since World War II (see figure 3)

humanity has significantly reduced ecosystem resilience by reducing biological diversity, by land degradation, overuse of marine ecosystems, emissions of pollutants and climate change, and altering the magnitude, frequency, and duration of disturbances with which animal and plant life has evolved. The combined and often synergistic effects of those pressures have increased the vulnerability of many ecosystems to disturbances that they could previously cope with. As a consequence, ecosystems may suddenly shift from desired to less desired states in terms of their capacity to generate essential ecosystem services (see examples in figure 7).

Box 1: Scenarios on economic growth and resource demand

The Swedish Environmental Advisory Council (Miljövårdsberedningen) performed a study in 2007 which illustrates how a rapidly growing global economy will result in a dramatic increase in resource demand. The growth forecasts used in the study points to a three or fourfold increase in the global economy over the next fifty years. The study goes through a number of scenarios on potential impacts on the demand for biological resources, such as forest and agricultural products, freshwater and fish as well as the demand for energy and the impacts on the climate. Overall conclusions include:

- Fish consumption per capita will continue to increase in the world. Studies from the UN Food and Agriculture Organization (FAO) indicate that the demand for fish will increase by approximately 30 per cent in the next twenty years. This increase in demand will probably have to be met through fish farming since the catching of wild fish has stagnated and the trend is pointing downwards. There is a risk that the scope of catching wild fish will have markedly decreased by the year 2050.

- The need for freshwater, which already is a scarce resource in many regions, may increase by 50 per cent globally as the population grows and incomes increase. When people become better off, their diets change and tend to contain more meat, which is water-demanding to produce.

- Demand for industrial timber for paper, sawn wood products and wood-based panels is projected to more than double in the next fifty years. The consumption of paper will increase fourfold according to the scenario but the assumption is also that the recycling of paper will increase from the current 40 per cent to approximately 80 per cent. The need for forest raw materials will increase dramatically both for industrial purposes as well as a source of energy. This may lead to a more intensive use of land and conflicts between different user interests, e.g. the need of land for agriculture, bioenergy production or conservation purposes.

- The demand for energy will increase threefold by the year 2050 (in line with the highest level scenarios in the reports of the IPCC). This may lead to drastic increases in CO_2 emissions if we do not radically change our energy systems. Emissions are already about two to four times higher than what can be permitted in 50 to 100 years time if we are to achieve the EU goal of a maximum increase in temperature of two degrees. By the year 2050, societies will not only have to halve their emissions but also satisfy a much greater global demand for energy. Bioenergy, which may replace fossil energy sources and mitigate global warming, requires major land surfaces and a great deal of water. Even if an area corresponding to four to seven times the agricultural area of Europe were used, it would not be possible to meet more than 15-20 per cent of future global energy needs. Moreover, the water required would equal that of the entire food production system.

- The world GDP will continue to grow rapidly and the production systems will continue to produce goods and services as present. Since these scenarios points to a rapid increase of resource demand it is unknown how the ecosystems will respond to such increase in pressure. The study implicitly assumes that there are no feed-back links between resource production and economic growth. If regime shifts drastically change resource production, this will potentially also influence the scenarios for economic growth.

Source: Scenarios on economic growth and resource demand. Background report to the Swedish Environmental Advisory Council memorandum 2007:1

2 The rationale for resilience

The sustainability agenda has changed dramatically over the past few years. Two key reasons are (1) the escalating human pressure on natural resources and ecosystem functions and (2) the rapid advance in Earth system and sustainability science. As stated above (section 1.1–1.2) this has resulted in growing evidence of the fundamental role played by nature as the life support base for human well-being and societal development. Moreover, nature provides individual households, communities, societies and the global community with resilience to deal with social and environmental shocks, including securing a sustained flow of critical ecosystem services. Hence, it is in the self-interest of people to account for and nurture this capacity thereby enhancing the likelihood of a continued prosperous social and economic development.

Climate change has arisen as the prime example of global environmental change, but there are many other areas subject to exponential and accelerated change over the past 50 years reflecting the rapid expansion especially since World War II (see fig 3 below).

As shown by the UN 2005 Millennium Ecosystem Assessment, the same trends of change can be observed for the Earths ecosystems, including loss of resilience of marine and coastal environments, biodiversity loss, deforestation and land degradation, unsustainable freshwater use and global nutrient cycles. Hence, humanity has reached a new phase in the stewardship of the Planet – the global phase of sustainability, which will require novel ways of governing and managing the ecological life-support base and the global commons.

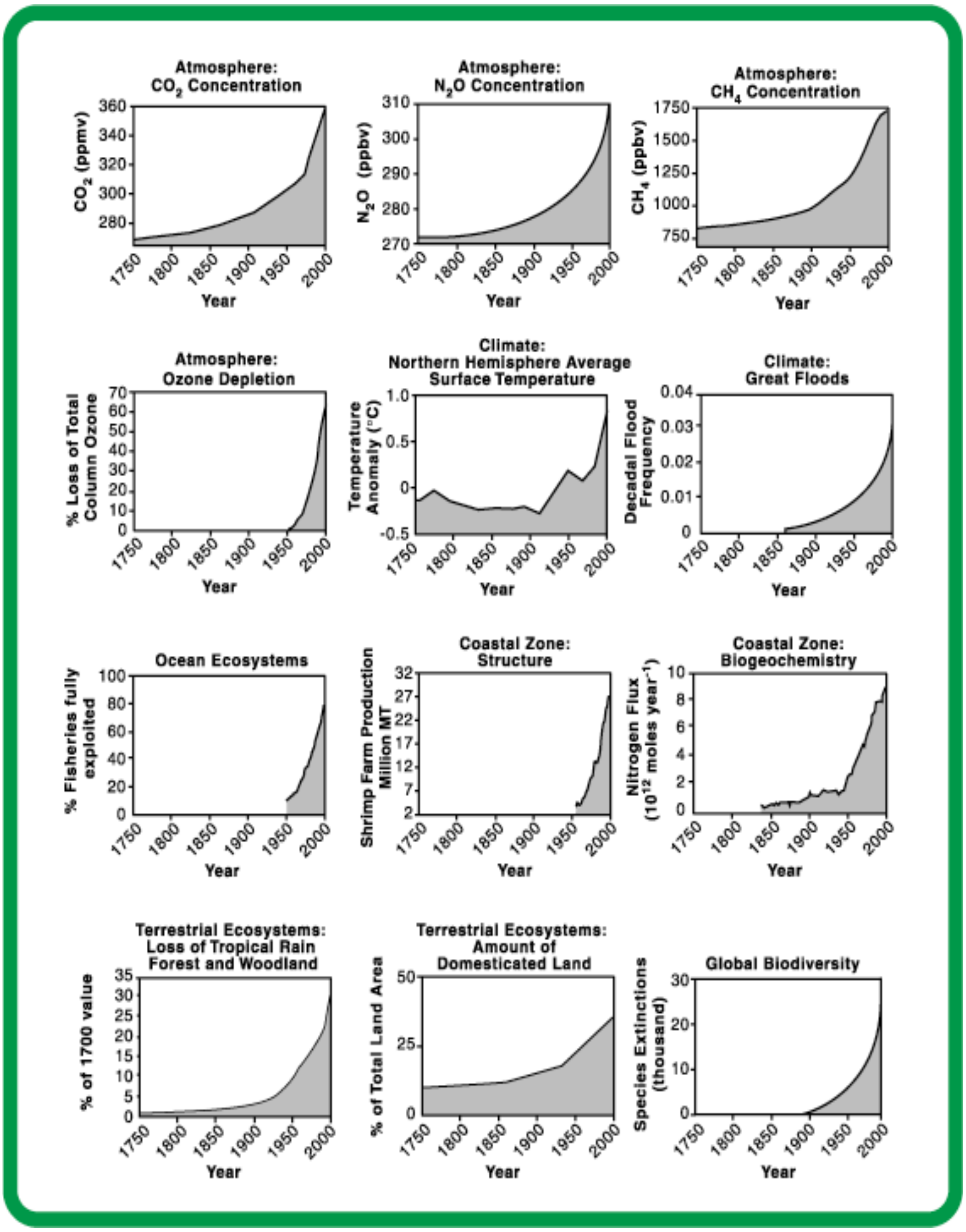


Fig 3: "The great acceleration" of the human enterprise from 1950s and onwards. Exponential growth of pressure as a result of the outscaling of the industrial revolution after the 2nd world war, combined with demographic growth and improvements in human wealth (Source: Steffen et al., 2004).

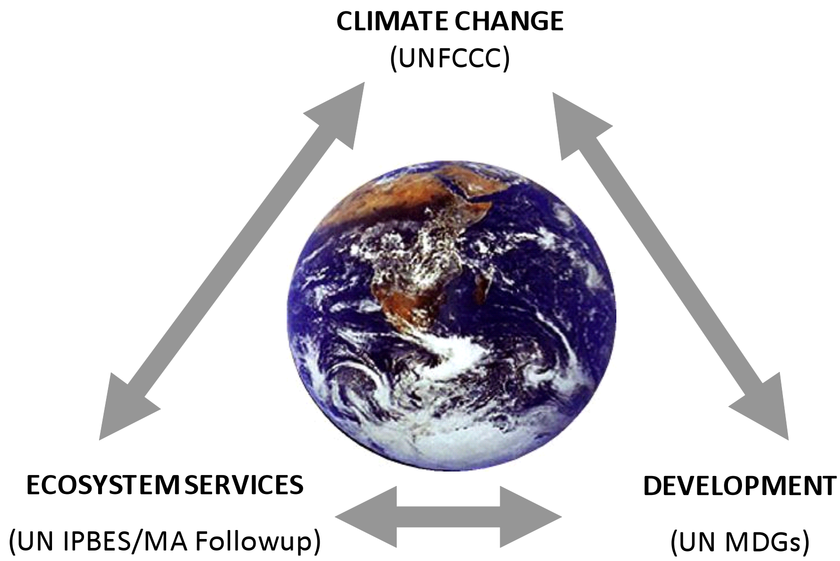


Figure 4. Three closely interdependent UN policy processes with limited interrelations: the UN Framework Convention on Climate Change, the UN Millennium Development process (with the Millennium Development Goals) and the UN Millennium Ecosystem Assessment (which includes also the Convention on Biodiversity and the MA-follow up with the proposed Intergovernmental science-policy platform on biodiversity and ecosystem services (IPBES) as well as the Potsdam Initiative on the Economics of biodiversity/Ecosystem services).

2.1 An increasingly globalised and turbulent world

As mentioned above, ample and increasing evidence from climate change research shows that the planet is warming (IPCC, 2007), with changes in the frequencies and intensities of drought, rainfall and major floods as well as spread and emergence of diseases. These changes have already started to entail significant impacts on many of the world's ecosystems, including coral reefs, tropical forests, ecosystems in the arctic region and dryland agroecosystems.

These ongoing climatic and ecological changes are, together with population growth, rapid urbanisation and globalisation, key drivers of human vulnerability to natural disasters. Consequently, natural disasters caused by storms, fire and flooding have become more common in recent years. This is not only because human-induced climate change have increased the number of extreme weather events, but also due to the fact that we have altered many natural systems so much that their resilience and ability to protect us from disturbance is greatly diminished. Forests, for example, reduce landslides and floods, and play a key role in stabilizing climate. Coral reefs and mangroves act as natural barriers against hurricanes and tidal surges. Yet another crucial factor behind this changing pattern is that human population growth has forced people and economic activities to settle in vulnerable areas. If resilience continues to decrease as we strive to increase production efficiencies, the frequency of regional catastrophes will escalate accordingly

Altogether the Earth might be approaching a number of ‘climate related tipping points’ this century (See fig below; Lenton et al., 2008). A ‘tipping point’ is a critical threshold at which a small change in human activity can have large, long-term consequences for the Earth’s climate, e.g. a small rise in temperature can cause abrupt changes in the environment that unleash runaway global warming that will be beyond our control. This implies that our societies must avoid being lulled into a false sense of security as global change may appear to be a slow and gradual process on human scales. Lenton and his colleagues list nine regions around the world where human

activities could kick- start abrupt and potentially irreversible changes within 100 years. These include: collapse of the Indian summer monsoon; disruption of the West African monsoon; and dieback of the Amazon rainforest. The latter is due to the combined effect of global warming and deforestation that is projected to reduce rainfall in the region. Models predict dieback of the rainforest to occur under three to four degrees Celsius global warming within fifty years. The damage will release billions of tons of carbon into the atmosphere, creating a vicious cycle that will worsen both warming and forest degradation in the region.

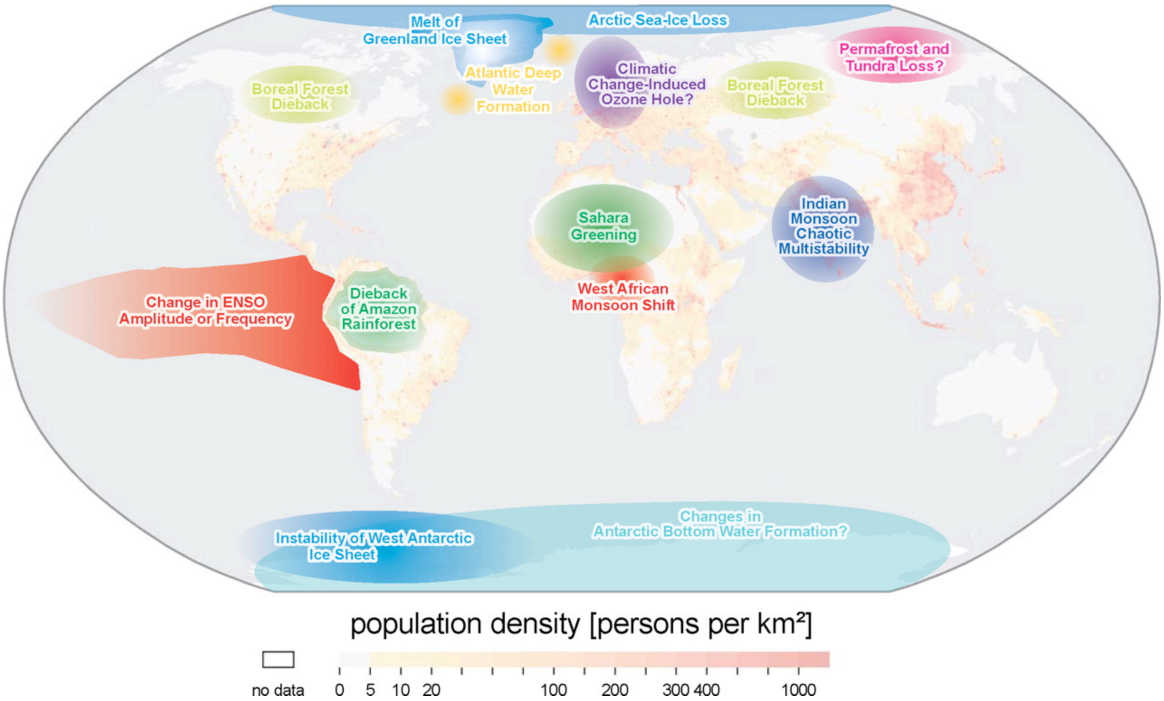


Figure 5: Map of potential policy-relevant tipping points in the climate system overlain on global population density (Source: Lenton et al., 2008). A 'tipping point' is a critical threshold at which a small change in human activity can have large, long-term consequences for the Earth's climate. The nine regions depicted here are places where human activities could kick- start abrupt and potentially irreversible changes within 100 years. Excluded from the map are systems in which any threshold appears inaccessible this century (e.g., East Antarctic Ice Sheet) or the qualitative change would appear beyond this millennium (e.g., marine methane hydrates). Question marks indicate systems whose status as tipping elements is particularly uncertain.

2.2 Planetary boundaries

Human activities are now capable in many cases of triggering regime shifts in the Earth's switch and choke points (Steffen et al. 2004). In the worst case scenario this could imply the crossing of potentially catastrophic thresholds entailing abrupt environmental change in continental to planetary scale systems. Effects would include sea level increases of several meters, a collapse of agricultural systems in dry regions, a total loss of coral reefs and the dry up of the Amazon rainforest. Given this power, humankind has an ethical responsibility to apply the precautionary principle to steer the human enterprise away from such planetary risks. This requires a much deeper understanding of the dynamics of the Earth System.

In the same way that we humans need to act decisively at a body temperature of 41° C, we need to figure out key ecological and geophysical boundaries of the Planet, which, if crossed, shifts Earth

into a different system state. Around such a threshold the situation may appear stable, but even a small additional perturbation can tip the system to a new undesirable and often irreversible state. In particular, we need to identify the critical zones surrounding these planetary boundaries and monitor appropriate indicators that can sense if a threshold is being approached. Staying within planetary boundaries is a precondition for sustainable development and provides a frame for the operation of the human enterprise.

The degree of uncertainty in quantitatively defining planetary boundaries is high, related to limits in our scientific understanding, difficulties in predicting self-regulating feedbacks, and the consequences for a particular boundary of transgressing other boundaries.

So far, identified planetary boundaries include climate change, ocean acidification, stratospheric ozone, biogeochemical cycles of nitrogen and phosphorous, global freshwater use, land use system change, biodiversity, chemical pollution and atmospheric aerosol loading (Rockström et al., in preparation). This boundary-setting approach opens up for several opportunities. It operationalises an Earth systems perspective on global sustainability by considering a group of key interacting parameters, rather than reducing complexity by focusing on individual parameters and sub-systems. It emphasizes the global nature of the human challenge and captures global-level risks that cannot be effectively dealt with at national and sub-global institutional and governance levels. It focuses on determining "safe" boundaries, or "guardrails", within which human development (well-being, security, wealth, and technology) can flourish, instead of focusing on the disastrous risks facing humanity. While ensuring that humanity stays within "safe" boundaries is by no means an easy task, this approach provides a constructive foundation for governance and management in a globalised world.

It seems like we now are capable of tipping the planet into devastating conditions for our own development. How to avoid this unpleasant future presents a major challenge for humanity. Recent research suggests that we will have to increase the resilience of our integrated social-ecological systems considerably to be able to stay within the planetary boundaries and cope with future climate change and other components of global change. To do that we need first, to abandon the perception and worldview that make us behave as if our development is independent of ecosystems and the constraints of the biosphere. Second, social and economic development must actively start to promote instead of further degrade the resilience of the Earth system and its capacity to generate the biogeophysical foundation for human wellbeing.

2.3 The natural capital basis for human wellbeing

Ecosystem services are the benefits people obtain from ecosystems (MA 2005, see Table 2). In this respect, ecosystems are living natural capital assets that, if properly managed, produce a flow of vital services to human societies (see table 2). Some of these, such as the provisioning services (or goods) like food, timber and fresh water, are well-known and routinely included in economic valuations, poverty reduction strategies and decision-making at large. Regulating services (e.g. carbon sequestration, storm protection and pollination) or the cultural services (e.g. recreation and spiritual values) are, on the other hand often overlooked because they are not traded in the market or internalized in traditional cost-benefit analyses. The term natural capital was coined to represent these natural assets that economists, governments, and corporations tend to leave off the balance sheets and is further presented in section 6 in relation to economic values, economics and resilience.

In recent years a range of reports, with the UN Millennium Ecosystem Assessment (MA) at the forefront, have shown how the ability of ecosystems to secure human welfare has declined. At the present time, 60% of ecosystem services are already being overexploited or threatened due to e.g. damage to habitats, invading species, eutrophication and environmental pollutants (see section 3.3). The accelerating changes in world climate pose an additional threat.

Now, many argue that we are facing a historic juncture in which the limits to increased wealth are not the lack of conventional form of capital assets (machines, buildings and infrastructure), but the dwindling resilience of natural capital. Along this line, the MA concluded that degradation of ecosystem services presents a significant threat to achieving the Millennium Development Goals, worsening poverty and causing social conflicts.

As this natural capital is being rapidly depleted, there is a growing need to find a new system of development – a system that realises the full value of ecosystem services and that takes the resilience and dynamics of natural capital into account.

2.4 The Millennium Ecosystem Assessment

The UN-initiated study, Millennium Ecosystem Assessment (MA), was a unique global survey that was called for by United Nations Secretary-General Kofi Annan at the turn of the millennium. In a series of seven reports, published in year 2005 and 2006, the MA assessed the state of global ecosystems and their role for human well-being. The MA-reports focus on the interactions between social and ecological systems and brings ecosystems back to the heart of development decision-making by documenting how much we gain from nature every day in the form of ecosystem goods and services (see table below). The study, spanning the local to the global scale and carried out by 1,360 experts in 95 nations, delivers a stark message to policymakers in developing as well as developed countries. The four main findings of the MA-reports are:

1. Due to rapidly growing demands for food, freshwater, timber, fibre and fuel, humans have changed ecosystems faster and more extensively in the past 50 years than ever before. About 60 percent of the ecosystem services that support human well-being are being degraded or used unsustainably.

2. The degradation of ecosystem services could get significantly worse during the next 50 years. This will be a barrier to the achievement of the Millennium Development Goals.

3. The changes made to ecosystems have contributed to substantial gains in human well-being and economic development, but these gains have been achieved through the degradation of many ecosystem services, increased risks of abrupt changes, and increased poverty for certain groups of people.

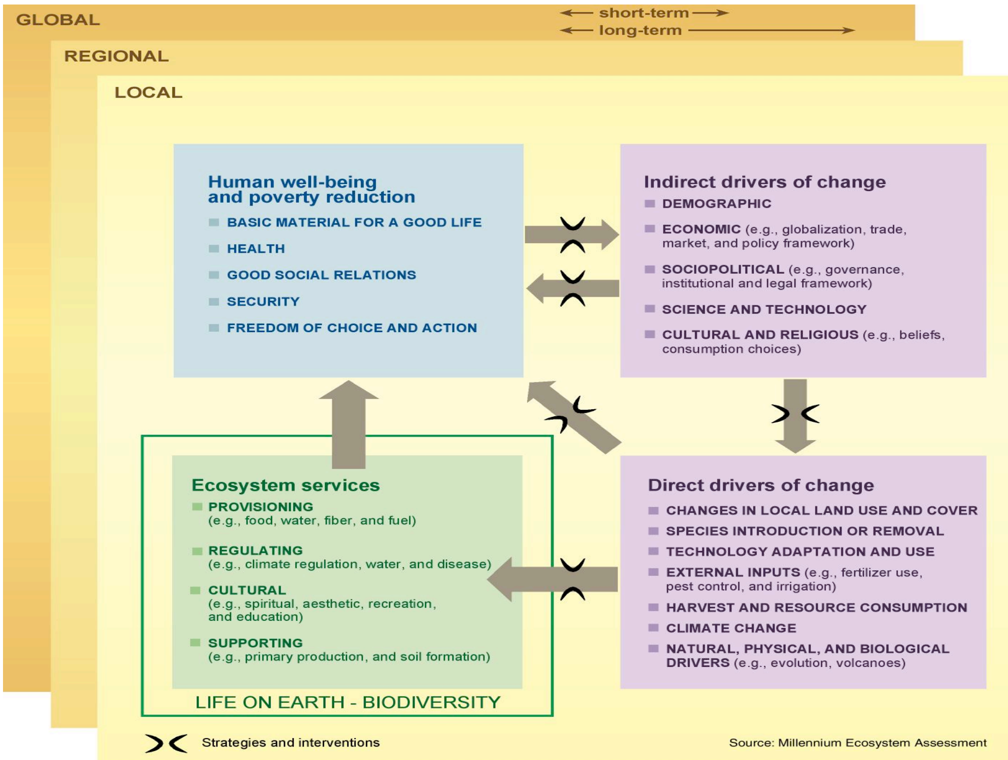
4. Reversing the degradation of ecosystems while meeting increasing demands for their services is a challenge. It can be partially met in the future, but requires substantial changes in policy, institutions and practice.

Table 2: List of ecosystem services, as defined in the Millennium Ecosystem Assessment (adapted from World Resources Institute, 2008)

Service	Subcategory	Definition	Examples
Provisioning services: The goods or products obtained from ecosystems such as food, timber and fiber.			
Food	Crops	Cultivated plants or agricultural produce that are harvested by people for human or animal consumption as food	· Grains · Vegetables · Fruit
	Livestock	Animals raised for domestic or commercial consumption or use	· Chicken · Pigs · Cattle
	Capture fisheries	Wild fish captured through trawling and other nonfarming methods	· Cod · Crabs · Tuna
	Aquaculture	Fish, shellfish, and/or plants that are bred and reared in ponds, enclosures, and other forms of freshwater or saltwater confinement for purposes of harvesting	· Shrimp · Oysters · Salmon
	Wild foods	Edible plant and animal species gathered or captured in the wild	· Fruit and nuts · Fungi · Bushmeat
Fiber	Timber and other wood fiber	Products made from trees harvested from natural forest ecosystems, plantations, or nonforested lands	· Industrial roundwood · Wood pulp · Paper
	Other fibers (e.g., cotton, hemp, silk)	Nonwood and nonfuel fibers extracted from the natural environment for a variety of uses	· Textiles (clothing, linen, accessories) · Cordage (twine, rope)
Biomass fuel (wood fuel)		Biological material derived from living or recently living organisms—both plant and animal—that serves as a source of energy	· Fuelwood and charcoal · Grain for ethanol production · Dung
Freshwater		Inland bodies of water, groundwater, rainwater, and surface waters for household, industrial, and agricultural uses	· Freshwater for drinking, cleaning, cooling, industrial processes, electricity generation, or mode of transportation
Genetic resources		Genes and genetic information used for animal breeding, plant improvement, and biotechnology	· Genes used to increase crop resistance
Biochemicals, natural medicines, and pharmaceuticals		Medicines, biocides, food additives, and other biological materials derived from ecosystems for commercial or domestic use	· Echinacea, ginseng, garlic · Paclitaxel as basis for cancer drugs · Tree extracts used for pest control
Regulating services including supporting services: Regulating services are the benefits obtained from an ecosystem's control of natural processes such as climate, disease, erosion, water flows, and pollination, as well as protection from natural hazards. Regulating services normally include also Supporting services, i.e. the natural processes such as nutrient cycling and primary production that maintain the other services.			
Air quality regulation		Influence ecosystems have on air quality by emitting chemicals to the atmosphere (i.e., serving as a "source") or extracting chemicals from the atmosphere (i.e., serving as a "sink").	· Lakes serve as a sink for industrial emissions of sulphur compounds · Vegetation fires emit particulates, ground-level ozone, and volatile organic compounds
Climate regulation	Global	Influence ecosystems have on global climate by emitting greenhouse gases or aerosols to the atmosphere or by absorbing greenhouse gases or aerosols from the atmosphere	· Forests capture and store carbon dioxide · Cattle and rice paddies emit methane
	Regional and local	Influence ecosystems have on local or regional temperature, precipitation, and other climatic factors	· Forests can impact regional rainfall levels · Lakes regulate humidity levels and influence frequency of frosts, important for agriculture
	Carbon sequestrati on	The extraction of carbon dioxide from the atmosphere serving as a sink	· Expanding areas of boreal forests, increases the sink · Deforestation in the tropics, decreases the sink · Ocean carbon sequestration
Water regulation		Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge, particularly in terms of the water storage potential of the ecosystem or landscape	- Permeable soil facilitates aquifer recharge - River floodplains and wetlands retain water—which can decrease flooding during runoff peaks—reducing the need for engineered flood control infrastructure

Service	Subcategory	Definition	Examples
Erosion regulation		Role vegetative cover plays in soil retention	- Vegetation such as grass and trees prevents soil loss due to wind and rain and siltation of waterways - Forests on slopes hold soil in place, thereby preventing landslides
Water purification and waste treatment		Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through soil and subsoil processes	- Wetlands remove harmful pollutants from water by trapping metals and organic materials - Soil microbes degrade organic waste, rendering it less harmful
Disease regulation		Influence that ecosystems have on the incidence and abundance of human pathogens	- Some intact forests reduce the occurrence of standing water—a breeding area for mosquitoes—which lowers the prevalence of malaria
Pest regulation		Influence ecosystems have on the prevalence of crop and livestock pests and diseases	- Predators from nearby forests—such as bats, toads, and snakes—consume crop pests
Pollination		Role ecosystems play in transferring pollen from male to female flower parts	- Bees from nearby forests pollinate crops
Natural hazard regulation		Capacity for ecosystems to reduce the damage caused by natural disasters such as hurricanes and to maintain natural fire frequency and intensity	- Mangrove forests and coral reefs protect coastlines from storm surges - Biological decomposition processes reduce potential fuel for wildfires
Nutrient cycling		Role ecosystems play in the flow and recycling of nutrients (e.g., nitrogen, sulphur, phosphorus, carbon) through processes such as decomposition and/or absorption	· Decomposition of organic matter contributes to soil fertility
Cultural services: The nonmaterial benefits obtained from ecosystems such as recreation, spiritual values, and aesthetic enjoyment.			
Recreation and ecotourism		Recreational pleasure people derive from natural or cultivated ecosystems	- Hiking, camping, and bird watching - Going on safari
Spiritual, religious and ethical values		Spiritual, religious, aesthetic, intrinsic, “existence,” or other values people attach to ecosystems, landscapes, or species	- Spiritual fulfilment derived from sacred lands and rivers - Belief that all species are worth protecting regardless of their utility to people—”biodiversity for biodiversity's sake”
Aesthetic values		The beauty and aesthetic values of nature in all its appearances.	- Beauty of nature, from a molecule to a flower to a forest

Box 2. The Millennium Ecosystem Assessment (MA) framework



The MA framework (see fig above) shows a number of links between the condition of ecosystems and human well-being. It depicts direct and indirect drivers of change and their respective impacts on ecosystem services, human well-being and poverty reduction. The framework helps to address the risks and opportunities related to ecosystem services and identifies groups of people who rely on these services. Furthermore, the framework can identify ecosystem service trade -offs in decision-making and help target responses by the most effective level of governance (local to global). It incorporates both formal scientific information and traditional/local knowledge and assesses the use and effectiveness of a range of options for responding to the need to sustainably use, conserve and restore ecosystems and the services they provide. The framework also distinguishes between different temporal scales (days to decades or even centuries) and spatial scales (local, national, regional or global).

2.5 Interconnected social-ecological systems

Our perspective is that the earth system is a fully integrated system of natural and social sub-systems, in which the continued provision of ecosystem goods and services is fundamental to human well-being, what we refer to as integrated social-ecological systems. Social-ecological systems present complex dynamics with alternate stable states, tipping points and regime shifts. And of paramount importance is the recognition that the dynamics of social-ecological systems are inherently non-linear, giving rise to sudden changes (tipping points) that demarcate alternate stable states of the system. The non-linear dynamics fundamentally change the sustainability agenda and highlight the notion of resilience, the capacity of a social-ecological system (such as an urban area, farming systems or lake) to cope with disturbance (such as a flood or

pandemics) while maintaining structure, function and the ability to move on and continue developing.

The integration of the human and the environmental dimensions for ecosystem stewardship is still in its infancy, so analyses of social-ecological systems are not as well developed as those of social or ecological systems alone (Costanza 1991, Ludwig et al. 2001, Westley et al. 2002). It has amply been shown that focusing only on the ecological aspects as a basis for decision making for sustainability leads to conclusions that are too narrow often with misleading policy recommendations. Ecosystems can pass a threshold and shift from one state into another, often triggered by human actions (Folke et al. 2004). When a lake shifts from a clearwater state attractive for fishing and recreation to a state of undesired algal blooms and muddy waters, it may look like an ecologically irreversible transition. The Baltic Sea may be such a case as well. However, if there is sufficient adaptive capacity in the social system to avoid the shift or respond to it and foster social actions that return the lake or the Baltic Sea to a clearwater state, the social-ecological system is still resilient to such changes (Carpenter and Brock 2004, Bodin and Norberg 2005).

Similarly, a focus that is restricted to the social dimension of ecosystem stewardship without understanding how it is coupled to ecosystem dynamics will not be sufficient for sustainable outcomes. One of many down to earth examples is the development of fishing cooperatives in Belize, considered to be a social success, because it improved the social and economic conditions of people in the country. However, the local mobilization of coastal fishers into socially desirable and economically effective fishing cooperatives became a magnet of fishing efforts to capture economic rent and resulted in a short-term resource-exploitation boom of lobster and conch, causing large-scale resource-use problems and increased vulnerability of the fishermen and the coastal society as a whole. Such local examples serve as an illustration of the trap that the global society is currently facing. The current common focus on the economic and social dimensions alone to measure and direct societal progress without accounting for natural capital has degraded the life support capacity of ecosystems on which human well-being depends.

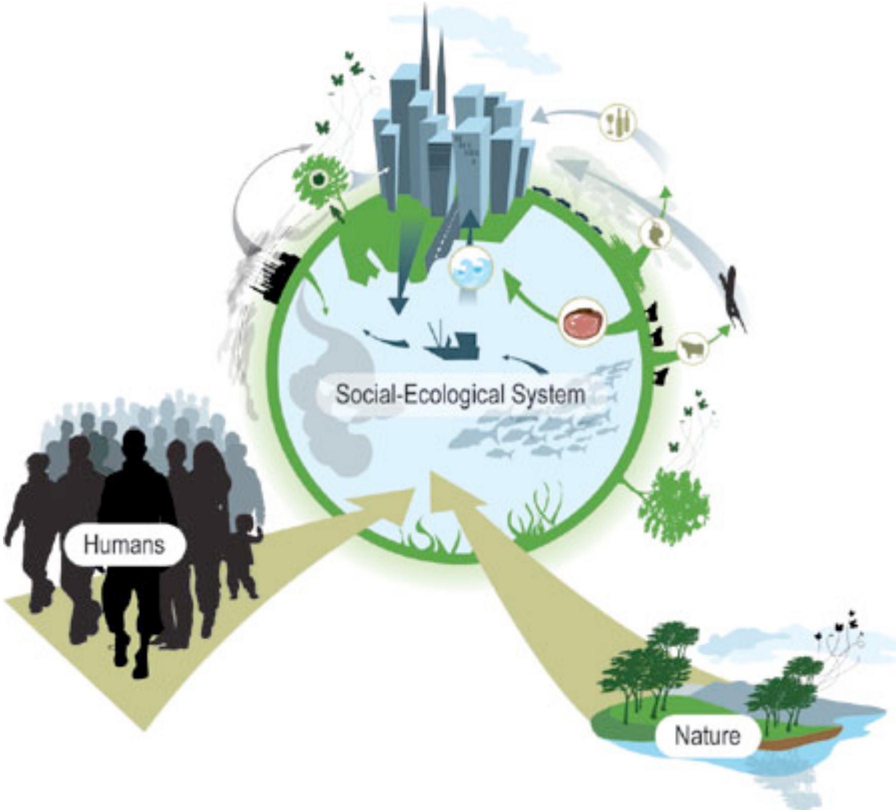


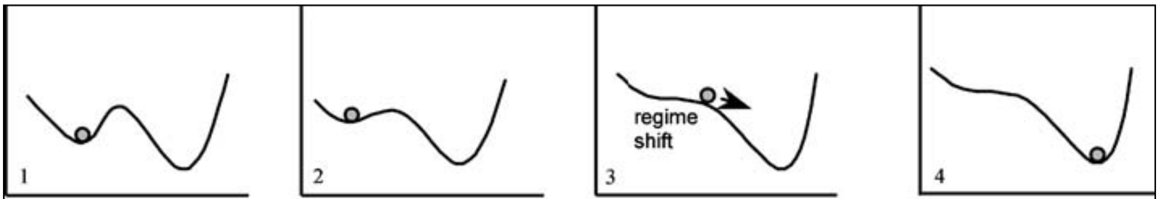
Figure 6: Humans and nature coexist in increasingly interwoven and globalised social-ecological systems. The whole earth system can be seen as a fully integrated system of human and natural sub-systems in which the continued provision of ecosystem goods and services is fundamental to human well-being (Illustration by Christine Clifstock).

2.6 Complex systems – examples of threshold effects

The earlier world-view of nature and society as systems near equilibrium is being replaced by a dynamic view, which emphasizes complex non-linear relations between entities under continuous change and facing discontinuities and uncertainty from complexes or suites of synergistic stresses and shocks. Theories of complex systems portray systems not as deterministic, predictable and mechanistic, but as process-dependent organic ones with feedbacks among multiple scales that allow these systems to selforganize (e.g. Levin, 1999). The study of complex adaptive systems attempts to explain how complex structures and patterns of interaction can arise from disorder through simple but powerful rules that guide change. Complex systems are self-organizing, meaning that the macroscopic system properties and patterns that emerge from the interactions among components feedback to influence the subsequent development of those interactions. Self-organization can lead to systems being far from equilibrium, characterized by multiple possible outcomes of management (Levin 1999).

Human behaviours that reduce the adaptive capacity to deal with interactions between gradual and abrupt change may push social-ecological systems toward a threshold that precipitates a shift into an alternative state. The existence of thresholds between different states (sometimes called 'regimes' or 'domains of attraction' in the resilience

literature) has been described for several ecological systems (Scheffer et al. 2001, see "thresholds database" at www.resalliance.org, and see figure below). Experience suggests that critical ecosystem transitions are increasingly occurring as a consequence of human actions and seem to be more common in human-dominated landscapes and seascapes (Folke et al. 2004).



clear-water lakes	phosphorous accum-ulation in agricultural soil and lake mud	flooding, warming, overexploitation of predators	turbid-water lakes
coral-dominated reefs	overfishing, coastal eutrophication	disease, bleaching hurricane	algae-dominated reefs
grassland	fire prevention	good rains, continu-ous heavy grazing	shrub-bushland
grassland	hunting of herbivores	disease	woodland
kelp forests	functional elimination of apex predators	thermal event, storm, disease,	sea urchin dominance
pine forest	microclimate and soil changes, loss of pine regeneration	decreased fire frequency, increased fire intensity	oak forest
seagrass beds	removal of grazers, lack of hurricanes, salinity moderation, spatial homogenization	thermal event	phytoplankton blooms
tropical lake with sub-merged vegetation	nutrient accumulation during dry spells	nutrient release with water table rise	floating-plant dominance

Figure 7: The "ball and cup" model illustrating resilience loss followed by phase shifts in different ecosystems. 1: Original system state. 2: The stability domain is affected by various changes in the environment and/or in management practices that reduce the resilience of the system (the cup becomes shallower) 3: A disturbance that previously could be absorbed moves the system into a undesirable state with a loss of ecosystem services. 4: The system is essentially locked in an undesirable state generating fewer ecosystem services to human society. The ball resembles the ecological community and the cup is referred to as the stability domain or basin of attraction. The ball is resting at the bottom of the cup but can be moved up along the side of the cup by a disturbance. The shift from one stability domain to another often involves passing a threshold (from Folke et al. 2004)

Regime shifts are discussed also in social systems, for example in the development of scientific knowledge systems (e.g. 'paradigm shifts', Kuhn 1962), and such shifts interrelate in complex ways with traditional knowledge systems and with shifting

policies and management of natural resources. Regime shifts have been described for legal systems, institutions, societies (Redman 1999), and collapse of whole cultures (Diamond 2005).

There are those that argue that society, in particular western societies, are in a transition from a world view of humans in control of and conqueror of nature to a recognition that society and well-being is dependent on a resilient biosphere. This regime shift in perception seems to be triggered by the recent widespread climate challenge, illuminated through phenomena like the climate scientists of IPCC winning the Nobel Peace Prize in 2007, the Al Gore climate movie in 2006 and the Stern Review on the Economics of Climate Change in 2006.

2.7 The new view on biological diversity

Research on ecosystem resilience has provided deeper understanding of the role of biological diversity in ecosystem dynamics. Biological diversity is essential in the self-organizing ability of complex adaptive systems (Levin, 1999) both in terms of absorbing disturbance and in regenerating and reorganizing the system following disturbance (Folke et al., 2004). In 1991, the newly established Beijer International Institute of Ecological Economics at the Royal Swedish Academy of Sciences initiated a research programme on the ecology and economics of biodiversity loss (Perrings et al., 1992), in particular, the role and value of biodiversity in supplying ecosystem services (Barbier et al., 1994). At that time insights from ecosystem ecologists had started to emerge on aspects of biodiversity in ecosystem function and redundancy in ecosystem dynamics and development. An ecological synthesis on the role of biodiversity in the functioning of ecosystems was developed by Holling, Schindler, Walker and Roughgarden (1995) as part of the Beijer Institute programme, where they argued that only a small set of species and physical processes are essential in forming the structure and overall behaviour of ecosystems.

Hence, it is not the number of species per se that helps sustain an ecosystem in a certain state or domain of attraction, but rather the existence of species groupings, or functional groups (e.g. predators, herbivores, pollinators, decomposers, water flow modifiers, nutrient transporters) with different and often overlapping characteristics in relation to physical processes (Walker et al., 1999; Hooper et al., 2005). Species that may seem redundant and unnecessary for ecosystem functioning during certain stages of ecosystem development may become of critical importance for regenerating and reorganizing the system after disturbance and disruption (Folke et al., 1996; Bellwood et al., 2004). They form essential ingredients of resilience, reorganize the system and turn crises into opportunities.

In addition, variability in responses of species within functional groups to environmental change is critical to ecosystem resilience (Chapin et al., 1997) a property referred to as response diversity (Elmqvist et al., 2003). Biological diversity can enhance the resilience of desirable ecosystem states, because different species will respond differently to a disturbance (response diversity). Response diversity is the diversity of responses to environmental change among species contributing to the same ecosystem function. In the Baltic Sea for instance, species A may be sensitive to changes in temperature (e.g. pike-perch and many other freshwater fish species whose

growth or survival are enhanced by warmer temperatures), whereas species B may be sensitive to lowered salinity (e.g. marine fish species as cod). If these species perform a similar function, they will contribute to the system capacity to withstand environmental changes. Similarly, studies on coral reefs indicate that reefs with more diverse compositions of grazers may be more resilient to disturbance than reefs with less diverse grazing fauna (Bellwood et al. 2004). The Storm "Gudrun" in 2005 in southern Sweden illustrated that the low diversity spruce forests were less resilient to the storm than forest stands with deciduous trees (with deeper root systems which enhance stability). The loss of coral reefs in the Caribbean and forests stands in southern Sweden has had substantial economic consequences. They illustrate the long term costs of changes landscapes and seascapes into monocultures for short term benefits.

2.8 Uncertainty and surprise

Recognizing and accepting the uncertainty of future conditions is a central part of incorporating resilience thinking into ecosystem stewardship. We are nowhere close to a predictive understanding of the complex interactions and feedbacks that govern trajectories of change in social-ecological systems nor able to anticipate the future human actions that will modify these trajectories. There are several sources of uncertainty, only some of which can be readily reduced. Both scientific research and the observations and experience of managers and other people provide data that inform our understanding. However, there are many uncertainties regarding the validity of any dataset and its representativeness of the real world. Models, both quantitative computer models and conceptual models of how the world works, also have many uncertainties in assumptions and structure. Surrounding these uncertainties in data and models are uncertainties in other factors that we know to be important but for which we have neither data nor models—the "known unknowns". There are also "unknown unknowns" that we cannot anticipate—the surprises that inevitably occur (Kinzig et al. 2003, Carpenter et al. 2009).

There are several types of surprises (Gunderson 2003). Local surprises may be created by a narrow breadth of experience with a particular system, either temporally or spatially. People tend to respond to these surprises by forming subjective probabilities that are updated when new information becomes available. Based on these estimates, there is a wide range of adaptations to risk that are economically rational to individuals, including risk-reducing strategies and risk-spreading or risk-pooling among independent individuals. Local surprises are manageable by individuals and groups of individuals. Their detection requires a comprehensive systems perspective (e.g., an ecosystem rather than a single-species approach). Adaptation-to-risk strategies fail when surprises are not local. Cross-scale surprises occur when there are cross-scale interactions, such as when local variables coalesce to generate an unanticipated regional or global pattern, or when a process exhibits contagion (as with fire, insect outbreak, and disease). Cross-scale surprises often occur as the unintended consequences of the independent actions of many individual agents who are managing at different scales. Although individual responses are generally ineffective, individuals acting in concert can address these surprises, if appropriate cross-scale institutions are available or are readily formed. True-novelty surprises constitute never-before-experienced phenomena for which strict pre-adaptation is impossible. However, systems that have developed mechanisms for reorganization, learning, and renewal following sudden change may be able to cope effectively with true-novelty surprises. These are the social-ecological features that nurture resilience to deal with unexpected change. Directional change in the context of global and climatic change creates a situation of increased likelihood of unknowable surprises. It is within these sources of uncertainty and surprise that ecosystem stewardship must function and where a resilience approach becomes essential (Chapin et al. 2009).

3 What is resilience?

Resilience is the capacity of a system to deal with change and continue to develop. It describes the long-term capacity of a system, e.g., a community, society or ecosystem, to deal with change and withstand shocks while retaining essentially the same structure and function. It covers three key features:

1) ***Persistence*** (sometimes called buffer capacity): the capacity of a system to maintain structure and function when faced with shocks and change (e.g. for a forest or coastal town to withstand the shock of a hurricane);
2) ***Adaptability:*** the capacity of people in a social-ecological system to manage resilience through collective action in order to stay within a desired state during periods of change (e.g. the ability to safeguard current food production systems under climate change);
3) ***Transformability***: the capacity of people in a social-ecological system to learn, innovate and transform in periods of crisis in order to create a new system when ecological, political, social or economic conditions make the existing system untenable (e.g. turning the current financial crisis into an opportunity to transform the global economy and jump start the age of green economics).

3.1 The Resilience Lens

Resilience is more of a perspective – or a way of thinking – than a measure. In some, particular context-specific ways it is possible to measure it, but in a general sense, the 'resilience lens' provides a new framework for analyzing social-ecological systems in a changing world facing many uncertainties and challenges. It represents an area of explorative research under rapid development with major policy implications for sustainable development. It acknowledges, as mentioned in section 1.2, that most of the unwelcome surprises in natural resource-use systems stem from a failure of the ruling management paradigm; a command-and-control approach underlain by flawed assumptions that ecosystems and natural resources are predictable and easily controlled.

Our economic and institutional systems accordingly assume that development is predictable, controllable and follows more or less linear trajectories. Science increasingly shows that this assumption is incorrect. Different systems, from the Baltic Sea to the degraded Sahel region, present trends of long periods of seemingly limited change, and sudden periods of abrupt change. The likely flip of the Baltic Sea is such an example, with a probably flip from a cod rich/nutrient poor/aerobic state to a cod poor/eutrophied/anaerobic state (Miljövårdberedningen, 2005). The drama, as shown in the collapse of the cod fisheries off the coast of Newfoundland, is that systems crossing thresholds into new, undesirable states, tend to get stuck there, or are extremely difficult and expensive to reverse.

A resilience way of thinking offers an alternative approach. It assumes that social-ecological systems behave as complex adaptive systems (Levin 1998, and see section 3.5). That is, they are self-organising systems. But there are limits to their capacity to self-organise, and if these limits are exceeded their self-organising behaviour propels them towards some new state. The limits are due to the fact that complex adaptive systems have non-linear dynamics, with consequent threshold effects between alternate system regimes.

If there is no possibility of thresholds and state shifts (cf Scheffer and Carpenter 2003) there is no fundamental problem in resource management or governance, because the system is always smoothly reversible within current technology and resource constraints. If a mistake is made, or the stakeholders change their minds (values), there is no fundamental difficulty in moving to another state of the system. In non-linear systems, however, the likelihood of alternate system states is high. A shift (intended or unintended) from one to the other can be irreversible, or very hard to reverse. The resilience lens therefore places a clear emphasis on identifying alternate states (or 'regimes') and the capacity to avoid or change the thresholds between them. Some of these system states are desirable from a human perspective and others are undesirable, depending on the flows of goods and services. And the same state may be deemed desirable and undesirable by different stakeholder groups.

Three features – persistence, adaptability and transformability – determine the system's resilience and therefore the likelihood of state shifts. Resilience governance and management is therefore concerned with learning how to avoid (or to cross) thresholds between alternate states, how to influence the positions of the thresholds, and how to transform to a different kind of system when it is necessary.

3.1.1 Persistence

Persistence (sometimes called buffer capacity) is the capacity of a system to maintain structure and function when faced with shocks and change (e.g. for a forest or coastal town to withstand the shock of a hurricane) – in other words, to stay in the current state or 'regime'. In this respect, resilience analysis is about understanding which state the system is in, how close to a threshold it is. It is also about understanding how external drivers (rainfall, exchange rates) and internal processes (plant succession, predator–prey cycles, management practices) lead to changes in the persistence of the current state.

There is an emerging scientific worry that global warming may trigger regime shifts in ecosystems, and thereby cause vicious cycles accelerating climate change. This concern is particularly important because during the past 50 years ecosystems have provided an immense ecosystem service to humanity by absorbing approximately 50 % of the greenhouse gas emissions, i.e., reducing by half the real human impact on the climate system.

Hysteresis is a particular feature of threshold changes. It happens when loss of resilience is followed by "true regime shifts", as seen in e.g. The Baltic Sea that seems to be currently locked in a human-induced undesirable eutrophic state (Österblom et al., 2007). That is, even if the perturbation is removed or reversed (e.g. by a reduction in nutrient load or reduced fishing pressure), the system may follow a nonlinear response and ultimately may only approximate the original state. Hence, hysteresis describes the difference between an ecosystem's response to a perturbation and its removal, or reversal, over time (see diagrams below).

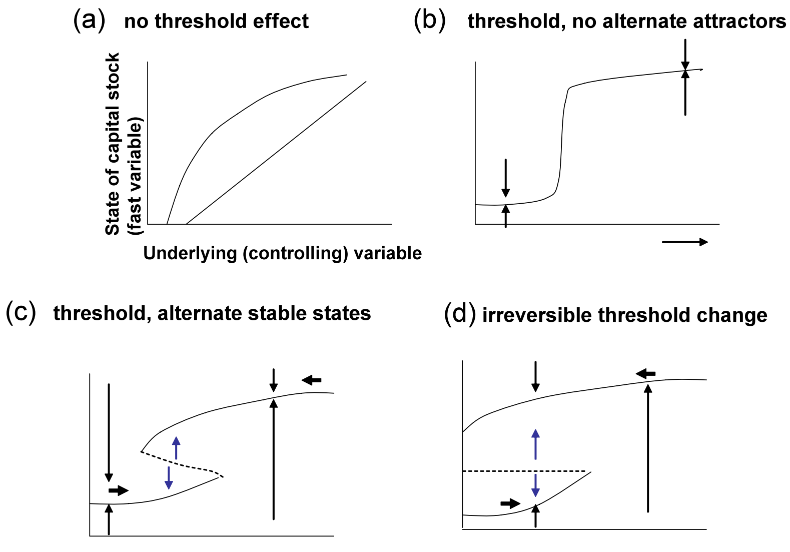


Fig 8. The four possible responses of the equilibrium state of a system (here denoted by the state of a capital stock, e.g. turbidity of the Baltic Sea) to changes in an underlying, controlling variable (e.g. nutrient load). The equilibrium state is the amount of the capital stock that the system will eventually settle at if the controlling variable is held constant at any particular level.

The lateral arrows in (c) and (d) represent the direction of change. (c) and (d) involve hysteretic responses, where the return path is different from the development path, resulting in two possible stable (equilibrium) states for the same level of the controlling variable (see text). (From Walker et al, in press).

The existence of alternate stable states is what makes the concept of resilience so important. The bigger the difference between the levels of the two states, and the bigger the hysteresis effect (i.e., the more the controlling variable needs to be reversed before the state of the system 'flips' back), the greater is the significance of that particular aspect of resilience.

3.1.2 Adaptation and Adaptability

In a resilience context adaptation involves learning about the existence of thresholds, learning how to stay away from them (if the current system state is a desired one), and learning how to move thresholds away so as to increase the safe amount of change the system can undergo. It is about understanding how external drivers (rainfall, exchange rates) and internal processes (plant succession, predator–prey cycles, management practices) lead to changes in the persistence of the current state. Adaptability, then, is the capacity of the actors in the system to manage resilience.

Box 3: Powerless spectators, coping actors or adaptive managers?

How do communities react to changes in climate and ecosystems? It all depends on aspects like technological options, institutions, leadership, motivation and how much they invest in long-term management of ecosystem services.

Many poor local communities around the world now have to adapt because they face enormous challenges due to ecological and climatic changes resulting in conflicts, new policies and changes in livelihoods. The appropriateness of their responses varies a lot, conclude Christo Fabricius, Rhodes University, South Africa, and his colleagues in a study from 2007 in the journal *Ecology and Society.*

Based on their synthesis, three broad categories of adaptive communities are identified: ***(1) "Powerless spectator"*** communities have a low adaptive capacity as they lack financial and/or technological options. Moreover, they often lack natural resources, skills, institutions, and networks. ***(2) "Coping actors"***, on the other hand, do have the capacity to adapt, but they do not really perceive the close coupling between their society and ecological systems. Combined with a lack of leadership, vision, and motivation, this typically leads to short term responses. The third category identified, ***(3) "Adaptive manager"*** communities, have both adaptive capacity and governance capacity, and they invest in the long-term management of ecosystem services. This requires features like leadership, vision, the formation of knowledge networks and high levels of motivation.

Such adaptive managers are better equipped to deal with conflicts, make difficult trade-offs between their short- and long-term well-being, and implement rules for ecosystem management. This improves the capacity of the ecosystem to continue providing services.

Short-term coping responses, on the other hand, tend to lead to reduced adaptive capacity so that communities' options for coping with change (political, economic, or ecological) are diminished or lost, argue the authors. The end result is far too often that they become trapped in a downward spiral of increased vulnerability. In the face of global change we all have to become more of adaptive managers, the study concludes.

Source: Fabricius, C., C. Folke, G. Cundill, and L. Schultz. 2007. Powerless spectators, coping actors, and adaptive co-managers: a synthesis of the role of communities in ecosystem management. Ecology and Society 12(1): 29. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art29/

A characteristic feature of complex adaptive systems is self-organization without intent (Levin 1998), and although the dynamics of SESs are dominated by individual human actors (or collective action by groups) who do exhibit intent, the system as a whole does not (as in the case of a market). Nevertheless, because human actions dominate in SESs, adaptability of the system is mainly a function of the social component – the collective capacity of individuals and groups acting to manage the system (see box 3 above). Their actions influence resilience, either intentionally or unintentionally. Their collective capacity to manage resilience, intentionally, determines whether they can successfully avoid crossing into an undesirable system regime, or cross back into a desirable one. (Note that, being internal to the system, the changes actors induce can feed back to changes in their values and actions).

There are four ways actors can influence resilience, corresponding to the four aspects of resilience. They can (1) move thresholds away from or closer to the current state of the system, (2) move the current state of the system away from or closer to the threshold, or (3) make the threshold more difficult or easier to reach. In addition, actors can (4) manage cross-scale interactions to avoid or generate loss of resilience at the largest and most socially catastrophic scales.

Box 4: Social Learning for governance of social-ecological systems

Uncertainty calls for adaptive approaches and systems of continuous learning for interpreting and responding to environmental and social change. Conflicting perceptions among stakeholders and a need for fundamental shifts in understanding and behaviour also point to learning as a fundamental part of successful governance. Learning that takes shape through interactions and deliberations and involves revision of belief systems, including values and emotions, is often called social learning. In the resource management and environmental policy literature, social learning has become increasingly recognized as a prerequisite for lasting changes in behavior and therefore an important complement to conventional policy instruments.

Social learning processes have been studied extensively both in the context of co-management of natural resources and as a feature of organizations dealing with global environmental change. There is also increasing recognition in the literature of the importance of links between governance levels.

The conditions that favor social learning include participation, dialogue, trust, and social networks that cut across various communities of practice. An example of the latter are boundary organizations with participation from the science and policy spheres. In contrast to one-way communication of expert knowledge, the emphasis is shifted to joint production of knowledge and practices as a way to enhance their credibility, legitimacy, and salience across stakeholder groups by involving multiple actors in the learning process. With many environmental problems being both global and local in character, a major challenge is to create social learning processes that can bridge local, national and global perspectives.

Ongoing research at the Stockholm Resilience Centre addresses the role and characteristics of social learning in the governance of social-ecological systems by studying networks, leadership, and participatory processes, including how learning is affected by linkages across scales.

3.1.3 Transformation and Transformability

One aspect of resilience that is now gaining increased interest is the capacity of human-natural systems to transform when conditions make the existing system unsustainable. In a growing portion of the world the need is actually to transform, not to make the existing system regime more resilient. That is, the only option may be to transform into a different kind of system – one defined by new state variables, or the old state variables supplemented by new ones. *Transformability* is the capacity of people in a social-ecological system to create such transformational change. It requires a capacity to learn, innovate and transform in periods of crisis when ecological, economic, or social conditions make continuation of the existing system untenable. It means introducing new components and new ways of making a living, and often a change in the scales that define the system. New variables can either be introduced or allowed to emerge.

"We are now on the threshold of a global transformation – the age of green economics",

Ban Ki-Moon, UN General Secretary

There are many examples of SESs becoming locked in and unable to transform until it is too late (salinized agricultural systems; dams, floodplains and flood control; forest fire suppression at ever larger scales). How can society develop transformability and avoid such lock-ins? In these situations building resilience is not the appropriate action, as this approach would simply amount to 'digging the hole deeper'. The question facing policy makers and planners will increasingly become: "which parts of our (locality, region, country) need enhanced resilience in order to ensure that their present states can continue, and which parts need to be transformed?"

Tensions may occur between maintaining the resilience of a desired current configuration in the face of known (and some unknown) shocks, and simultaneously building a capacity for transformability, should it be needed. How can we foster or maintain the flexibility that will be required to cope with unforeseen challenges? This is a new field and little is known about the attributes required for transformability, but they will likely emphasize novelty, diversity and organization in human capital - diversity of functional types (kinds of education, expertise, and occupations); trust, strengths, and variety in institutions; speeds and kinds of cross-scale communication. These all fall within the remit of adaptive governance, a good account of which is given in Dietz et al. (2003) and in Folke et al. (2005).

One example of the ability of humans to transform is the problems of state-shifts caused by invasive water hyacinths in lakes, ponds and waterways in many parts of the world. This beautiful flower produces large floating carpets of fleshy flowers that block waterways, clog irrigation canals, disrupt hydropower, decrease fishing and create habitat for disease-carrying mosquitoes. Instead of trying to combat this invasive species many now have started to show signs of transformability, that is, they innovate to make crisis an opportunity through developing different ways to use water hyacinths, in agricultural or alternative energy systems. For instance, due to their copious growth and rich concentrations of nutrients, the hyacinths can be used as fertilizer for the nutrient poor soils of Africa and as feed for livestock.

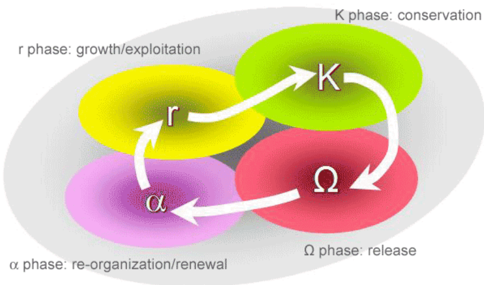
On a larger scale many now see the current financial crisis as an opportunity to transform the global economy. "We're now on the threshold of a global transformation – the age of green economics", said Ban Ki-Moon, the UN General Secretary, recently to Newsweek. Likewise, the new US president is planning to invest $15bn a year over the next decade in renewable energy, creating five million new green jobs that "pay well, can't be outsourced and help end the US dependence on foreign oil". In this way, the ecological and economic crises are integrally linked, even though one doesn't necessarily cause the other. Moreover, our societies' capacity to cope with the economic crisis is clearly reduced because of many decades of ecological degradation, and this diminished resilience affects the poor and most vulnerable populations the most.

Transformation is about moving out of unsustainable situations. The focus on transformation towards improved situations is a research frontier of social-ecological systems. It requires shifts in perceptions and actions towards active collaboration with the biosphere, recognizing that economic progress and societal development are intertwined with the capacity of life-support systems to sustain them. A major requirement for human well-being is to secure, restore and develop the capacity of ecosystems to generate ecosystem services (including food, timber, pollination, seed dispersal) since this capacity constitutes the very foundation for social and economic development.

Box 5: Adaptive cycles and panarchy – key aspects of resilience

Analyses of many, diverse social-ecological systems reveal that over time virtually all such systems tend to pass, repeatedly, through cycles consisting of four phases of structure and function. These four characteristic phases of an adaptive cycle are:

1. growth or exploitation (r)
2. conservation (K)
3. collapse or release (omega)
4. reorganization (alpha)



The arrows indicate the general pattern of the cycle, but deviations are possible (and are in fact quite frequent). The four phases can be seen as the contrast between the 'forward', reasonably predictive 'r' to 'K' pattern of dynamics, where capital accumulates, and the chaotic, unpredictable 'backloop' dynamics where bound up resources are released and creative opportunities arise for new development options. During the slow sequence from r to K, connectedness and stability increase and amounts of capital (e.g., nutrients and biomass in ecosystems, capital stocks and assets in a business) slowly accumulate and are sequestered. Competitive processes lead to a few species becoming dominant, with diversity retained in residual pockets preserved in a patchy landscape. In an economic or social system, it is the skills, networks of human relationships, and mutual trust that are incrementally developed and tested during the progression from r to K.

Practically all standard science and policy are based on the foreloop phases. The adaptive cycle, in contrast, focuses attention upon processes of destruction and reorganization, which are often neglected in favor of growth and conservation. A growing realisation that coupled systems of humans and nature tend to alternate between long periods of aggregation and

transformation of resources and shorter periods that create opportunities for innovation, is fundamental for understanding complex systems from cells to ecosystems to societies.

Moreover, adaptive cycles are nested in hierarchies across multiple time and space scales, representing a “panarchy”. Panarchy is the structure in which systems, of nature (e.g., forests) and of humans (e.g., capitalism), as well as combined human-natural systems (e.g., institutions that govern natural resource use), are interlinked in continual adaptive cycles. In essence, larger and slower components of the hierarchy provide the memory of the past and of the distant to allow recovery of smaller and faster adaptive cycles. For example, a forest can be seen as a hierarchy of levels ranging from the whole forest to a grove of trees, to individual trees, to each leaf. Each level undergoes adaptive cycles of change, e.g. the turnover rate of a forest may be hundreds of years, while the turnover rate of a leaf is one year. The parts and the whole are tightly interconnected. If a leaf is infected by a virulent parasite, the tree and perhaps the whole forest may suffer. Migrating birds connect forests across the globe to each other. Problems that arise in a forest may be due to activities half a planet away or may be the result of slow changes accumulated over centuries. Those managing and using forests or other ecosystems must understand these cross-scale interactions of panarchies and adaptive cycles. It is key to sustainable development.

4 Implications of resilience thinking

Observations from comparative analyses of resilience in various regions of the world (see, for example, Walker et al. 2006) highlight a number of recurring issues that a resilience approach to sustainable development needs to consider. In the following sections we go through a number of key attributes of governance and management for enhancing resilience of desired states through adaptability, or lowering resilience of an undesirable situation to make a transformation possible. We present a range of case studies where this approach has been used to promote sustainable development in social-ecological systems.

Box 6: Low-tech Water System Innovations promote resilient flow of food and other ecosystem services in semi-arid sub-Saharan Africa

Semi-arid and dry sub-humid sub-Saharan Africa (SSA) presents large challenges in terms of the Millennium Development Goals on eradicating poverty and hunger, while achieving environmental sustainability. The main livelihood in these regions is small-scale rainfed farming, but yield levels in current production systems are very low. The hydro-climate is a main limiting factor, but poor soils and land degradation also plays important roles.

Research by Stockholm Resilience Center and partner institutions in the Makanya catchment in northeastern Tanzania shows that the livelihood support of the surrounding ecosystems plays an important role for smallholders, especially in times of crisis. When crops failed due to drought in 2005-2006, more than 40% of the income in the area was generated from local ecosystem services, such as fodder for livestock, fiber products, wild fruits etc. This was just as important as the incomes from business, labor, and remittances were. Consequently,

strategies for agricultural intensification do not only need to promote productivity at field-scale, they should also nurture the productivity of the whole agro-ecosystem. The Makanya example further suggests that there has been a reinforcing feedback between declining on-farm productivity and declining quantity and quality of the surrounding resource base in the catchment area over the past half century. A number of interlinked social and biophysical driving forces, the dry-spell frequency being an important one, have pushed the system along this development path.

Meeting the MDGs on food and environment in dryland SSA will require that smallholder agro-ecosystems, as the one in Makanya, shift to more productive trajectories. Small-scale water system innovations, such as rainwater harvesting* and conservation tillage**, could potentially contribute towards this, by creating synergies between increased food production and improved generation of other ecosystem services.

One of the most widespread misconceptions of semiarid SSA is that there is no water. The problem is that the water that falls on the land rapidly runs off the soil and that the gullies dry up so quickly. Hence, there are great possibilities of ”closing the yield gap” between the actual yields achieved by farmers and the potential yields that could be met with a better management of the limited soil and water resources. Whereas conventional solutions have been to develop large-scale irrigation systems, several recent studies have shown that small-scale water retention systems tend to be more suitable in areas of the world where a large part of the population live in extreme poverty and are vulnerable to climate changes.

Hence, low-tech and small-scale innovations might promote both improved yield levels as well as greening of the surrounding ecosystems in the upper catchments (entailing increased flows of ecosystem services as carbon sequestration and erosion reduction). Less frequent dry-spell induced crop failure would also relieve some of the pressure on the surrounding resource base due to a lower resource outtake. Lastly, small-scale water system innovations may offer platforms for collective landscape management.

* The practice of catching and holding rain for later use during times of drought.

**A tillage practice that does not invert the soil and that leaves a protective amount of crop residue on the surface throughout the year, a practice which reduces erosion and retains water on land.

4.1 Probing the boundaries of resilience

In a nutshell, keeping things constant reduces resilience. A common objective of policies aimed at optimizing some particular product or outcome is to identify an ‘optimal’ state of the system, and then to somehow try and keep it in that particular state. In fact, keeping a system in one particular state leads to self-organised changes that make the system less and less resilient. As an example, preventing fire in a forest, in an attempt to keep it in its present state, leads eventually to the loss of those species that are able to withstand fire. They are out-competed by species that do not have to channel resources into attributes (thick bark, resistant cell structures, dormant stem buds) that enable them to resist or recover from fire. The longer fire is prevented, the more vulnerable the forest becomes to fire. Hence, to keep a forest resilient to fire it is necessary to periodically burn the forest at smaller scales. This was dramatically learned in Yellowstone National Park in the USA. Almost half of the Park burned down in one major fire in 1988, after decades of excluding fire and accumulation of burnable material. As knowledge accumulated, the use of “prescribed” fire grew and foresters now include fire as an appropriate tool in managing the forest.

Probing the boundaries of resilience is the core idea behind adaptive management of ecosystems and social-ecological systems. It requires understanding and knowledge about the ecosystem of concern, and this knowledge has to be built into monitoring, management and governance. For example, although necessary it is not sufficient to reduce fishing effort, or ban the fishery, to enable the cod stock of the Baltic Sea to recover. Such recovery requires timing between decreased fishing pressure and influx of salt water to the Baltic that improve the water quality and increase the success of cod recruitment (Österblom et al. 2007). Furthermore, the fishing pressure on predators that consume young cod (thereby constraining cod recovery), like sprat, could be increased during such periods.

Adaptive management implies that knowledge is continuously generated about such key interaction in ecosystems and built into management. Adaptive ecosystem management is an ongoing process, an organised way to deal with uncertainty and learn from management actions. Basically such adaptive management can be divided into:

- A conceptual system model, sometimes expressed as a computer simulation model that represents available knowledge and understanding of the system processes, structure and elements. It requires a manager to say, explicitly, how the system will respond to any given management action.
- A set of strategies that represents management policies or actions.
- A set of criteria for judging the success of the implementation of management actions and policies (i.e., for determining if the predicted response of the system was correct).
- A process that continuously evaluates and responds to the effects of management actions on the system and incorporates lessons learned in an improved “model” (understanding) of the system, and a new set of strategies to improve management.

Learning platforms that bring together people with diverse expertise and knowledge to make such understanding for sustainability and resilience building possible are part of the adaptive management perspective and a significant component of the emerging ecosystem-based approach to marine fisheries. The economic and political arenas need to make space and collaborate with such approaches if a sustainable flow of ecosystem services is to be achieved.

Box 7: Local communities key to resilient ecosystem management through local knowledge and quick response to change

Local people's knowledge of local resources and ecosystem dynamics is significant for management for resilience and sustainable supply of ecosystem services, a study from Stockholm Resilience Centre shows. The article, published in 2007 in the journal Environmental Conservation, investigates the role of local actors in ecosystem management in the area of the river basin Kristianstads Vattenrike located in southern Sweden. Based on interviews of the local actors, participatory observation and review of various written documentation, the study shows that engaging local actors may not only lower the transaction costs of sustained conservation but also improve incentives for sustained ecosystem mangement. This is because local actors, such as farmers and landowners, possess a great potential to conduct on-site management experiments, long-term place-based monitoring and provide quick responses to environmental change. As such, these local steward groups represent an undervalued and sometimes unrecognised source of knowledge and experience that can complement scientific knowledge.

Even though some local stakeholders may seem to have a narrow focus, aiming at favouring certain habitats or species, the activities of local actors need to be recognised as a potential source of stewardship of biodiversity and ecosystem services. In the study of Kristianstads Vattenrike, several hundred active local actors were identified, ranging from place-based farmers to national NGOs.
The researchers propose that governmental agencies and NGOs devoted to environmental conservation should take advantage of local steward groups and avoid policies and actions that exclude people from the land. Local groups should be given high priority and be applied in programmes like the EU Water Framework Directive and UNESCO's Man and the Biosphere reserves.

Source: Schultz L., Folke C., Olsson P. (2007) Enhancing ecosystem management through social-ecological inventories: lessons from Kristianstads Vattenrike, Sweden Environmental Conservation 34(2): 140-152

4.2 Avoid pushing problems up-scale

Making things resilience at one scale can reduce resilience at other scales. The most common expression of this effect is pushing problems up-scale.

As described earlier, social-ecological systems periodically exhibit times of abrupt change when experience is insufficient for understanding, consequences of actions are ambiguous and the future dynamics are uncertain. Having high levels of resilience during these times is crucial for sustainability of human well-being. For most of the time, however, change is gradual or incremental, and during these 'normal' periods of steady progress things move forward in roughly continuous and predictable ways. It is during these periods that resilience is often eroded, unwittingly, through focussing on resolving issues that are happening at local scales and on short time scales. In "resolving" these issues the problem is often, in fact, not resolved, but pushed up-scale, reducing resilience at these higher scales. The EU "butter mountain" of some years ago arose through trying to make individual farmers more resilient in the short term to fluctuations in the price of butter. Over time, the whole EU dairy industry became very vulnerable – it lost resilience to cope with market changes. The Australian "wool mountain" was stockpiled for the same reason, and when it eventually became clear that the wool industry was very vulnerable and the "floor price" for wool had to go, many hundreds of farmers were badly affected or went bankrupt, at one time, rather than having continuous small-scale adaptations (albeit rather costly, or at least uncomfortable) at the farm scale.

The loss of resilience at higher scales through this tendency to push problems up-scale leads to situations where there is a lack of resilience at the very time when it is needed – when a period of abrupt and chaotic change takes place.

4.3 Embracing uncertainty and surprise; using crises as opportunities

Resilience research addresses how systems assimilate disturbance and make use of change for innovation and development, while simultaneously maintaining characteristic structures and processes. Managing for resilience enhances the

likelihood of sustaining and developing desirable pathways for societal development in changing environments where the future is unpredictable and surprise is likely. Not only are forecasts uncertain, the usual statistical approaches will likely underestimate the uncertainties since key drivers like climate and technological change may change in non-linear ways. Therefore, plans to solve complex environmental problems should always include the likelihood of surprise. But, there is a tendency to emphasize known computable aspects of a problem and ignore the likelihood that unknown and unsuspected things will occur. The tendency to ignore the non-computable can be countered by considering a wide range of perspectives, encouraging transparency with regard to conflicting viewpoints, stimulating a diversity of models, and managing for the emergence of new syntheses that reorganize fragmentary knowledge.

Ecosystems and the services they provide are changing more than at any time in recorded history, and many drivers are intensifying. These trends suggest a future with more frequent, intense, and interconnected extreme and surprising events. Although environmental extreme events are now sometimes included in risk assessments (World Economic Forum 2007), we usually lack the information necessary to estimate the probabilities of the important ones and their cascading effects. All of this raises the urgency of building resilience to address future large impacts on ecosystems and people (Carpenter et al. 2009).

Many studies (e.g. Berkes et al., 2003; Olsson et al., 2008) suggest that crises, perceived or real, seem to trigger learning and knowledge generation and open up space for combinations of different experiences and new management actions, leading to new trajectories of resources and ecosystems. For example, threats of acidification, over fishing and disease successively initiated learning and generated knowledge and institutions for landscapes management among local groups in the Lake Racken catchment in western Sweden. In the Great Barrier Reef the whole governance system, involving actors from local fishermen all the way up to political leaders, took on a new direction of ecosystem-based management as a response to the perceived crises of climate change and other impacts on the reefs.

Crisis seems to trigger mobilization of social capital and social memory, resulting in new forms of governance systems appropriate to the new conditions. This has been referred to as building social capacity for resilience in social-ecological systems and it requires inducing change in social structures. Key individuals with strong leadership may catalyze opinion shifts and creative teams and actor groups that emerge into a large connected community of practitioners can prepare a social-ecological system for rapid change.

4.4 Cross-scale and cross-domain effects; multiple, interacting thresholds

It is obvious that we are living in a globalized world economically and socially. But it is less obvious that this is also the case ecologically. The figure below, about the development of shrimp farming in Thailand, provides an illustration. Shrimp farming has expanded tremendously during the last decades, predominantly by cutting down mangrove forests in coastal areas of tropical countries for the establishment of ponds

in which the shrimp is farmed. Farming shrimps requires fishmeal. Fishmeal comes from fish caught in the sea. Production of fish for fishmeal relies on marine productivity and resilience. The figure shows that Thai shrimp farming uses the production capacity of the main part of the Earth's productive marine ecosystems for the production of shrimps in the ponds. These shrimps are to a large extent exported and may end up on the plate of a customer in a sushi restaurant in Stockholm. Such trade flows are tightly linked with ecosystem productivity and resilience.

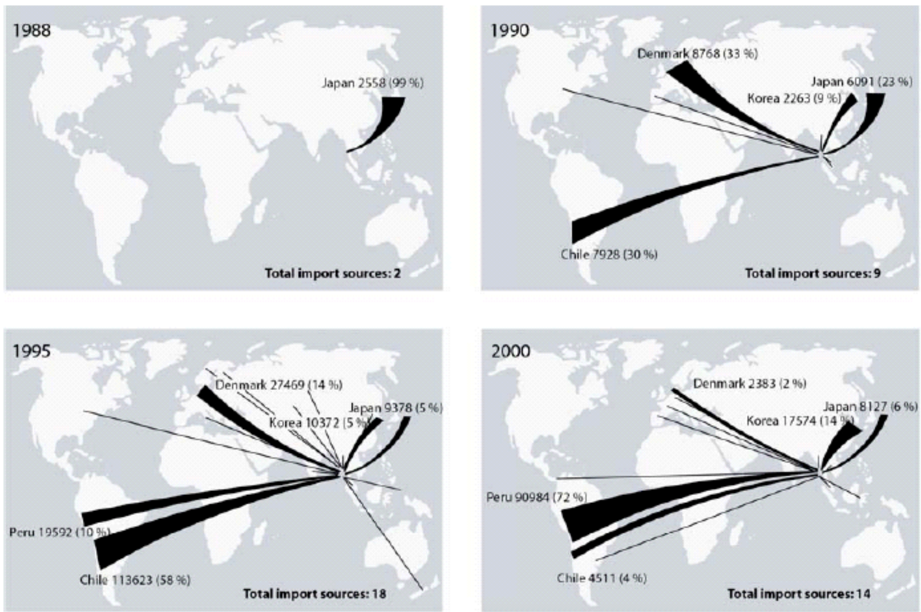


Figure 9. Fishmeal is used as feed in shrimp farming. Thailand shrimp farming exemplifies human dependence on the productive capacity of marine seas from all over the world, illustrating that we are not only globalised socially and economically but also ecologically (from Deutsch et al. 2007).

A sustained trade flow of such natural resources requires active stewardship of marine ecosystem resilience. Unfortunately, many fisheries have been exploited in an unsustainable pattern and many fish stocks are seriously overexploited. The demise of the cod fisheries off the east coast of North America is a classic example. Marine resource exploitation can deplete stocks faster than regulatory agencies can respond. Technological developments and a globalised world have made it possible for distant water fleets and mobile traders to operate like roving bandits, that is mobile agents that move on to other, unprotected resources when the first has been depleted, because global markets often fail to generate the self-interest that arises from attachment to place. Institutions with broad authority and a global perspective are needed to create a system with incentives for conservation. Roving banditry is different from most commons dilemmas in that a new dynamic has arisen in the globalized world: New markets can develop so rapidly that the speed of resource exploitation can overwhelm the ability of local institutions to respond. There have been few effective responses to this kind of exploitation, because the emergence of specialized export markets for hitherto unexploited stocks is almost always a surprise to managers. In the case of small or highly localized stocks, the resource may vanish even before the problem is noted. In the case of more widely distributed, relatively abundant species, serial

depletions of local stocks may be masked by spatial shifts in exploitation (Berkes et al. 2006).

Similar situations occur on land and may lead to loss of resilience and irreversible regime shifts. The production of palm oil is a current example. Bornean rainforests are ecologically driven by El Niño-induced droughts that trigger mast reproduction among trees, and though the fauna make use of it the amount of reproduction is such that new trees successfully establish. In this sense El Niño serves as a trigger for regenerating the rainforest and its biodiversity helps sustain forest resilience. The rainforest has evolved ecologically to use a crisis (El Niño Southern Oscillation events) as an opportunity for continuous development. Curran et al. (2004) have shown that in Indonesian Borneo (Kalimantan), concession-based timber extraction, oil palm plantation establishment, and weak institutions have resulted in highly fragmented and degraded forests, where mast events are too small and are swamped by demand seed predation. Fragmentation and land cover change is predominantly driven by demand for tropical timber and palm oil through international markets. This demand has changed El Niño events from regenerative to destructive forces in the Bornean landscape. Currently, El Niño disrupts fruiting of the rain forest trees, interrupts wildlife reproductive cycles, erodes the basis for rural livelihoods, and triggers droughts and wildfires (Curran et al. 2004). Page et al. (2002) estimated that the widespread El Niño related wildfires of Borneo in 1997 released between 0.81 and 2.57 gigatonnes (one billion metric tonnes) of carbon to the atmosphere equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels. A globalized world of human actions tipped the interplay between climate events and biodiversity into undesirable dynamics and created vulnerable landscapes in Borneo.

Hence, local groups and communities are subject to decision from regional levels and connected to global markets and vice versa. A social-ecological system can avoid vulnerability at one time scale through the technology it has adopted. Similarly, (as described above, where problems are pushed up-scale) resilience at one spatial extent can be subsidized from a broader scale, a common pattern in human cultural evolution and exacerbated by technology, capital markets and financial transfers that mask environmental feedbacks and may lead to crossing thresholds and regime shifts.

A recent study of a social-ecological system in Australia illustrates the existence of interdependent thresholds in social-ecological systems.

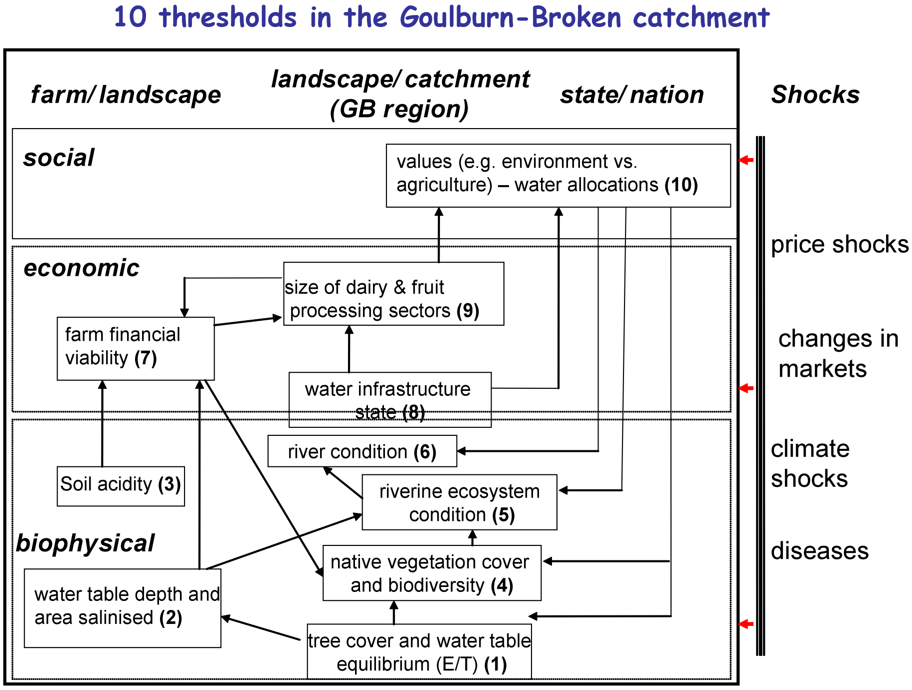


Figure 10. Ten known or suspected thresholds in the agro-ecosystem of the Goulburn Broken catchment in SE Australia. The arrows indicate possible cascading effects if the threshold concerned is crossed. The effect of one threshold being crossed may increase the probability of another being crossed (e.g., crossing threshold 1 increasases the likelihood of thresholds 2 and 4 being crossed), or it may decrease it (e.g., crossing threshold 7 can decrease the chance of crossing threshold 4, if farming is suspended) (Walker et al 2009)

Five important resilience features are illustrated by Fig 10:

i) there are multiple thresholds in social-ecological systems;

ii) they occur in the biophysical, social and economic domains, and at multiple scales;

iii) the thresholds interact – crossing one can lead to cascading effects;

iv) the "system" that needs to be managed is the whole 3-domain, 3-scale system. Trying to manage a single problem (threshold) on its own, at one scale, is unlikely to succeed;

v) the system is subjected to multiple kinds of shocks, and the first threshold to be crossed will depend on the kind of shock that first hits the system.

Box 8: Using Web 2.0 to build a unique knowledge base on how to put resilience theory into practice

The research organisation Resilience Alliance (RA) has developed a workbook: *Assessing and managing resilience in social-ecological systems: A practitioners workbook.* The workbook, which builds on research by RA members, provides a framework for assessing the resilience of social-ecological systems and considers options to set such interwoven systems of humans and nature on a sustainable trajectory. During the International Science and Policy conference, *Resilience 2008*, in Stockholm, a Wiki-version of the Workbook was launched. The Resilience Assessment Workbook Wiki is a collaborative project involving researchers and practitioners who seek a holistic approach to managing social-ecological systems for long-term sustainability. The wiki is aimed at those who have experience applying resilience concepts to social-ecological systems and who want to share their knowledge by contributing to the on-going development of the resilience assessment guide. The wiki is based on

Version 1.0 of the Practitioner's workbook Assessing and Managing Resilience in Social-Ecological Systems. New modules and examples will be added continuously to the wiki by a growing community of people who are doing resilience assessments in a variety of systems around the world.

One of the most recent examples of how the workbook approach can be used to build resilience in a heavily degraded social-ecological system is a workshop coordinated by the Mountain Societies Development Support Program (a project of the Aga Khan Foundation) in Dushanbe, Tajikistan, October 2008. Here, representatives from the RA led a five-day workshop in order to introduce the resilience concept and the workbook approach in preparation for a full resilience assessment that will take place in the spring 2009.

More at:
http://wiki.resalliance.org.

Box 9: Threshold effects in the Baltic Sea

The Baltic Sea is a semi-enclosed brackish sea where more than 85 million people in nine different countries inhabit the drainage basin. The sea is an important recreation area and supports a substantial fishery. These ecosystem services are supported by coastal habitats and agricultural practices which struggle to be sustainable. Most of the policies are mainly regulated at the European level (i.e. the Common Fisheries and Agricultural Policies, the Water Framework directive and the Marine Strategy Directive). The nature of the Baltic Sea also makes it strongly influenced by natural variations such as salinity.

The sea is an important route for transportation of oil and cargo, as well as for energy production and transport. Water quality is negatively affected by poor sewage treatment in some countries and substantial runoff of nutrients originating in agriculture. Overfishing (including substantial illegal fishing) has resulted in dwindling stocks of important commercial fish species. Over the course of the last century, regime shifts have been identified with regards to eutrophication (in the 1950s) and due to a combination of changes in climate and overfishing (1989-1990). Changes in climate resulted in deteriorated conditions for cod and improved conditions for sprat. At the same time, fishing for cod was intensive, reducing the resilience of the stock to changing environmental conditions. We may stand at a threshold for an additional regime shift due to changes in climate during the coming decades, as all species in the Baltic Sea are sensitive to the delicate balance between salt- and freshwater.

The Baltic Nest Institute at Stockholm Resilience Centre has provided decision support to HELCOM for a country allocation scheme aimed at reducing nutrient flows, to increase water quality, which was incorporated in the 2007 Baltic Sea Action Plan. This strategic Action plan can provide a framework for making the Baltic Sea a pilot area within the EU, illustrating initial steps to use an ecosystem approach towards reducing nutrients, but it requires additional political commitment if the Baltic is to be regarded as a positive example of marine governance with an ecosystem approach.

More at:
http://www.balticnest.org/

4.5 Help for change, vs. subsidies not to change

In the examples from 5.2, where local scale problems initiated a response that causes loss of resilience at higher scales, a resilience approach would not necessarily have denied help to individuals. But it would have considered the kind of help that maintains system resilience across scales. Commonly, this could involve help to change, rather than help to continue doing the same thing that has been creating the problem. In Australia, this is beginning to happen. Droughts are a common

occurrence in the rangelands, and instead of giving farmers money to buy in feed to keep their livestock during droughts (which kept the animals on the land, causing ecological degradation), help is now being tied to assistance to de-stock and to reduce the pressure of animals on the land.

4.6 General and specified resilience, and the need for both

There is a danger in focusing too much on known or suspected thresholds (such as those described in 5.4 for the Australian catchment example). If all the attention and resources of management are channeled into managing for the identified (specified) resilience and associated thresholds, the management may inadvertently be reducing resilience in other ways – resilience to completely novel ‘surprises’. There is therefore a need to consider both general and specified resilience. General resilience is determined by such attributes as diversity (natural and social), tightness of feedbacks, modularity (i.e., not been over-connected), openness (maintaining inflows and outflows), reserves, and overlapping functions. While it is reasonably straightforward to estimate the costs of maintaining general resilience (some form of foregone extra yield or profit that it entails), it is much harder to estimate the costs of *not* maintaining it (since it is unspecified).

A resilience approach to development therefore calls for two kinds of effort:
i) Attempting to understand and identify the controlling (often slowly changing) variables that are likely to have threshold effects, leading to unwanted and perhaps irreversible regime shifts. How will these variables respond to particular kinds of shocks and disturbances, and what attributes of the system can be enhanced to avoid exceeding particular thresholds?
ii) Given that there may be completely novel shocks, with system responses that are as yet unknown, how can the system be made generally more resilient?

Box 10: Resilience research findings integrated in government-led effort to triple the area of protected forests in Madagascar

The dry forests of southern Madagascar have a high level of plant endemism, with 95% of the species found nowhere else on the planet. The area, which is listed as one of the 200 most important ecological regions in the world, is increasingly being subject to thresholds and regime shifts from changing climate and global socioeconomic drivers. Ecosystem services, like food crop pollination is dependent on culturally protected but fragile networks of taboo systems, in turn deeply embedded in cultural values and beliefs. Through field work, empirical studies and extensive interviews the ecology of the ecosystem services has been studied by scientists from Stockholm Resilience Centre and the University of Antananarivo in Madagascar. Moreover, property rights, cultural and religious values, economic drivers, networks, management and social-ecological governance in relation to ecosystem services and resilience have also been investigated.

Overall, the interdisciplinary resilience research has resulted in a number of insights for stewardship of biodiversity and ecosystem services that have now been taken up for improved policy and governance of the Madagascar social-ecological systems through various international agreements and in national policies and implementations. One example is the research findings that protection through sacred "taboo" forests and unofficial land ownership agreements has helped to regenerate large areas of the dryland forest that was previously in decline. This knowledge of how social institutions might influence the protection

and regeneration of forests is now being integrated in a recent government-lead effort to triple the island's area of protected forests.

Source: Elmqvist T., M. Pyykönen, M. Tengö, F. Rakotondrasoa, E. Rabakonandrianina et al. 2007. Patterns of Loss and Regeneration of Tropical Dry Forest in Madagascar: The Social Institutional Context. PLoS ONE 2(5): e402.doi:10.1371/journal.pone.0000402

5 Economic challenges of the resilience approach

5.1 Acknowledging the importance and dynamics of natural capital

Relative to other forms of capital, natural capital is poorly understood, rarely monitored, and in many cases undergoing rapid degradation and depletion. One attempt to include the natural capital is a welfare index called "Inclusive Wealth" discussed by e.g. Arrow et al. (2004), based on a measure called Genuine Savings by economists. It includes not only the social value of manufactured capital, but also human and natural capital. The natural capital component of this Genuine Savings measure, as developed by the World Bank, includes commercial forests, oil and minerals, and the damage caused by the release of carbon dioxide. However, many other human benefits of natural ecosystems are not included in the index, such as water resources, fisheries, wetlands controlling floods, forests providing erosion control, generation of fertile soils, and insects pollinating crops. Nevertheless, including even a few components of natural capital leads to findings substantially different from contemporary economic measures like GDP. Some countries that seem to be performing well when looking at GNP or the Human Development Index have in fact become poorer, according to the Genuine Savings index.

Likewise, the recent interim report of the EU-project The Economics of Ecosystems and Biodiversity (TEEB) aims for a better understanding of the true economic value of the benefits we receive from natural capital. The work which will continue in 2009 and 2010 has for instance presented the results of a preliminary analysis of the costs of the loss of biodiversity and ecosystem services from forests. In the period 2000 to 2050, it is estimated that in the early years we are losing forest ecosystem services with a value equivalent to around 28 billion Euros each year, and this value increases over the period to 2050. The TEEB-report also emphasises that "the full economic significance of biodiversity and ecosystems does not figure in GDP statistics, but indirectly its contribution to livelihood and well-being can be estimated and recognized". One example put forward in the report is an "equity" focused analysis of ecosystem service losses for the people of India. It shows that accounting for ecosystem services adds "only 7.3%" to classical GDP (using 2002/03 accounts and exchange rates), but 57 % to "GDP of the Poor" (increases from US$ 60 to US$ 95). Moreover, it is also shown that if these services were degraded, the cost of replacing lost livelihood, equity adjusted, would be US$ 120 per capita.

Another interesting example of how natural capital can be acknowledged in an economic context is the Corporate Ecosystem Services Review (ESR) developed by

the World Resources Institute together with the World Business Council for Sustainable Development and the Meridian Institute. It is a structured methodology for corporate managers to proactively develop strategies for managing business risks and opportunities arising from their company's dependence and impact on ecosystem services. It has been described as a methodology to better understand, and profit from, the link between healthy ecosystems and the bottom line.

So far, however, virtually all attempts at including the natural capital of ecosystem services in economic valuations and the environmental management systems of companies have failed to acknowledge resilience and threshold effects in ecosystems. That is, whereas markets tend to react in a linear and predictable (at least in theory) manner to changes (as prices rise, demand falls), ecosystems often respond in nonlinear and abrupt ways (e.g. small change in phosphorous load can abruptly shift a lake from clear to turbid when thresholds are passed).

Hence, focusing on the production or valuation of ecosystem services will not lead to sustainable use by itself, because it does not address the dynamic capacity of ecosystems to uphold the supply of these goods and services. The challenge is to sustain the resilience of ecosystems – i.e. their long-term capacity to cope with disturbances and maintain an adequate supply of goods and services.

Box 11: Putting price tags on Nature's services: can we assign economic value to an ecosystem's resilience?

An ecosystem's services can often be more valuable than its goods. For instance, the value of forest services, like flood control, recreational values, recycling of rainfall and carbon dioxide uptake, can be several times more valuable than its timber yield (Millennium Ecosystem Assessment, 2005). Hence, even if forest clear cutting is profitable for a logging firm, it might involve large costs for society at large. Such market failures occur when market prices do not reflect the full social costs or benefits of a good or service. Therefore, many argue that the value of ecosystem services must be incorporated into market prices so nations can make rational, environmentally sustainable, economic choices. Economists assign values to non-marketed ecosystem services using several valuation methods such as calculating the cost of replacing them with technology, or assessing how much people would be willing to pay for them.

Some criticise these types of studies, arguing that the true value of nature's services comprises much more than their importance to the world economy; there are moral, ethical, and aesthetic reasons to protect nature. Others note that ecosystem services could never be traded in open commerce, which is how prices of conventional goods and services are determined. Moreover, basically all available valuation methods are based on human preferences and could therefore be regarded as unreliable when applied to environmental services with which the public is unfamiliar.

Another major criticism is that basically all attempts at including the natural capital of ecosystem services in economic valuations have failed to acknowledge resilience and threshold effects in ecosystems. The value of biodiversity in this broader sense - that it is a prerequisite for the ecosystem's long-term survival - is much higher than the value that can be assigned to the current production of goods and services. Many ecologists have emphasised this wider insurance value of diversity, but it is extremely difficult - not to say impossible - to capture in economic valuations.

Source: Daily,G.C: and others. 2000. The Value of Nature and the Nature of Value. *Science* 21;289(5478):395-6.

5.2 Rethinking efficiency, optimization and growth

The economic goal in western societies is to maximize human well-being. We have promoted technologies targeted at this goal with little consideration to the effects on ecosystems. Their resilience has been taken for granted. Today, when it is becoming increasingly obvious how human well-being depends on sustained ecosystem services, we need to rethink and redefine concepts like efficiency, optimization, and economic growth.

a) Efficiency: In periods of stability, it appears rational to cut "slack resources" and optimize with respect to the present stability regime. However, in turbulent times, some of these resources are crucial for renewal of the system and prevent collapse. Cutting out apparent redundancies is supposed to be efficient. It is in line with the idea of "just in time" manufacturing and marketing, eliminating "unnecessary" and costly stockpiles. This is fine as long as nothing changes. But if a crisis occurs, the system has no back up; resilience is low. In hindsight, we know that the opportunity costs (forgone net benefits) have been very high when we have converted wetlands to intensive agriculture, or used antibiotics to stimulate meat production. Loss of wetland ecosystem services has eroded resilience of the Baltic Sea and the excessive use of antibiotics has resulted in resistant bacteria that in turn have reduced our capacity to cure infections. If we want to maximize human well-being we need a better, holistic understanding of how opportunity costs are affected by ecosystem feedbacks.

b) Optimization: A general tendency in resource management systems has been to try to get the system into some perceived "optimal' state, and to keep it there. The optimal state is the one that will deliver the highest yields. A variant of this is to devise optimal pathways or patterns of use. Again, this works as long as nothing in the external environment changes, but optimization often results in the system being close to a threshold, and when an external shock occurs the results can be disastrous. Hence, resources and practices, for example agricultural management or financial markets, need to be optimized with respect to all phases of the adaptive cycle (see box 5).

c) Economic growth: The Millennium Ecosystem Assessment (MA) noted that "A number of countries that appeared to have positive growth in net savings (wealth) in 2001 actually experienced a loss in wealth when degradation of natural resources were factored into the accounts" (MA 2005, Synthesis Report). Including stocks of natural capital into national accounts is only the first step; assessing the resilience of these stocks (sustained delivery of ecosystem services) is a more difficult challenge but crucial for human well-being.

Internalization of externalities is a necessary first step for these redefinitions. Conventionally, such internalization is done from case to case, when cause-effect relations have been proved. However, on a human-dominated planet the uncertainty and time-delays disguise the fact that externalities are ubiquitous rather than exceptions. Therefore we need to broaden the analysis and pursue economic activities

with the best expected impacts on social-ecological systems (see section on The Lisbon Strategies).

If externalities of human activities are ubiquitous and threaten the sustainability of ecosystem services, humans need to become active stewards of these ecosystem services. We can no longer take for granted that mitigation of pollution and other stresses will automatically result in recovery of ecosystem services. When loss of resilience is complete, then ecosystem restoration is needed (for example the wetlands in Örebro city of Sweden). When resilience is eroded and thresholds approached, major investments in learning and adaptation are needed for active stewardship. Learning involves stakeholder collaboration for two reasons: taking into account different knowledge systems may provide a more comprehensive understanding social-ecological dynamics; and the adaptation and governance strategies that emerge from a learning process need to include stakeholders.

It should also be acknowledged that for some stakeholders, e.g. indigenous representatives, the concept of ecosystem services is not culturally accepted because it is regarded as being too anthropocentric. On the contrary many indigenous groups emphasise that biodiversity in itself has a value that should not be described as a service to humankind, advocating the opinion that the language in itself hijacks the perception of nature and reduces it to just being a commodity. However, the experience is that there is a growing general understanding also among these stakeholders of the need for translating the values of biodiversity into a language that is more easily understood by policymakers in the private and public sector, but only if the ecosystem services approach is implemented in society in a culturally appropriate and rights based manner.

To conclude, economic strategies for managing resilience include a broader understanding of the economic goals and means – human well-being, efficiency, optimization, and growth. Economic externalities should be systematically included in strategies, not as externalities but as integral parts of the production function. Finally, the sustainability of vital ecosystem services are today in such a bad state that active stewardship is needed. Economic policies and strategies for learning and adaptation are needed to sustain human well-being.

6 Governance challenges

As seen in the previous sections, society and nature represent truly interdependent systems (social-ecological systems), which are complex adaptive systems with cross scale and dynamic interactions. How can we steer such systems for sustainable development? How do we cope with the unavoidable uncertainties of projected climate change impacts, and possible non-linear ecosystem responses, which make conventional goal formulations, economic evaluations and long-term resource planning so difficult? One thing is certain; our governance systems must be transformed to better match the dynamics of the planet's biophysical systems and acknowledge the strong social-ecological interconnections (see box 12 below).

Contrary to what is often assumed by policymakers and governance scholars, large parts of the world are not characterized by linear and predictable behaviour. Surprise, abrupt change and thresholds constitute normality in ecosystems, but we still tend to

design legislation and organizations to manage forests, water resources, agricultural land, natural resources, as if they follow linear, predictable, and thereby easily controllable pathways. Moreover, our social, economical and ecological systems display “cascading dynamics", meaning that small-scale events might trigger larger changes that are difficult or even impossible to reverse – and where the transition is sharp and dramatic with effects that might cascade across administrational borders and spark off political crises of a national or even international scale. No wonder then that governments tend to fail in promptly detecting and overcoming abrupt changes like suddenly emerging epidemics, catastrophic shifts in natural systems, and economic crises. Such changes increasingly challenge how societies are governed at all political levels. At worst, policy-making can unintentionally enhance vulnerability to climate change, as in the Goulburn-Broken Catchment in southeastern Australia and the impacts of Hurricane Katrina in New Orleans.

As global environmental change accelerates a parallel fundamental shift has unfolded in the way we govern society (Duit and Galaz 2008). Traditional hierarchical and formal modes of public steering are slowly giving way to different schemes of state and non-state collaborations: public-private partnerships, collaborative efforts, policy entrepreneurs and participatory initiatives. But the steering challenges that come with these changes are difficult to foresee.

Box 12: The problem of fit: Governance systems must be transformed to better match the dynamics of the planet's biophysical systems

Why do governance systems fail to protect vital ecosystem functions and resources? Important external factors can include a lack of political interest, weak legislation, administrative fragmentation and inefficiency, and the presence of free-riding behavior. However, a lack of capacity to understand the behaviour of multiscale ecosystems and their associated services is a fundamental but seldom elaborated factor. Institutions and policy prescriptions that fail to acknowledge the strong interconnection between social and ecological systems run the risk of ending up with ill-founded advice that fail to tackle such emerging global problems as the loss of biological diversity, the degradation of forests and the overarching issue of climate change. See ‘table 5.1’ from Galaz et al (2008) below for examples of different kinds of misfits and their underlying mechanisms.

Table 5.1
Types of misfits between ecosystem dynamics and governance systems

Type of misfit	Definition and mechanism	Examples	Solution(s) suggested in the literature
Spatial	Institutional jurisdiction too small or too large to cover or affect the areal extent of the ecosystem(s) subject to the institution.	I. Administrative boundaries do not match hydrological boundaries, which creates collective-action problems, misallocation of responsibility, and hydrological and ecological degradation (Lundqvist 2004).	River basin/integrated water resources management (Global Water Partnership 2000) Bioregionalism (McGinnis, Woolley, and Gamman 1999)
	Institutional jurisdiction unable to cope with actors or drivers external or internal and important for maintaining the ecosystem(s) or process(es) affected by the institution; e.g., institutional arrangements can be “too large” when providing centrally defined “blueprints” that ignore existing local biophysical circumstances (Scott 1995).	II. Local institutions for management of sea urchin are unable to cope with the development of global markets and highly mobile “roving bandits” (Berkes et al. 2006). III. Central managers design rules and implement “one size fits all” institutions that are inappropriate to the local social or ecological context (Ostrom 1999).	II. Multiple-scale restraining institutions (Berkes et al. 2006) III. Collaborative, decentralized natural resource management (Wondolleck and Yaffee 2000) Adaptive comanagement (Olsson et al. 2004)

Temporal	Institution formed too early or too late to cause desired ecosystem effect(s).	IV. In the 1950s and 1960s, governments in the West African Sahel promoted agricultural and population development in areas with only temporary productivity due to above-average rainfall. As the area returns to its low-productive state, erosion, migration, and livelihood collapse result (Glantz 1976).	Early-warning systems and national preparedness plans (Wilhite 1996)
	Institution (and possibly the actor interaction it entails) produces decisions that assume a shorter or longer time span than those embedded in the biophysical system(s) affected; and/or social response is too fast, too slow, too short, or too long compared to the time taken for biophysical processes involved (Holling and Meffe 1996; Scheffer, Westley, and Brock 2003).	V. The speed of impacts of invasive species is not matched by the speed of response of institutions, resulting in possible severe ecological and health implications (Meyerson and Reaser 2003; Miller and Gunderson 2004).	Adaptive management (Walters 1986) Adaptive comanagement (Olsson, Folke, and Berkes 2004) Scenario planning (Peterson et al. 2003)

Source: Galaz, V., Olsson, P., Hahn T., Folke, C. and Svedin, U. 2008. The Problem of Fit among Biophysical Systems, Environmental and Resource Regimes, and Broader Governance Systems: Insights and Emerging Challenges. Chapter 5 in "Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers". Edited by Oran R. Young, Heike Schroeder and Leslie A. King, MIT Press, Massachusetts Institute of Technology, Cambridge, USA.

Resilience thinking calls for ways of governing that create space for flexible, innovative collaboration and open institutions that allow for learning and building capacity to cope with change. Such flexible institutional arrangements tend to be much better adapted for long-term survival than set prescriptions for resource use. Flexibility can also be enhanced by systems of governance that exist at multiple levels (so-called polycentric institutions) with some degree of autonomy complemented by modest overlaps in authority and capability. This type of diversified decision-making structure allows for testing of rules at different scales and contributes to the creation of institutional dynamics important for building resilience. It requires active involvement of local resource users, decision-makers and other interest groups in collectively devising common rules and regulation for sustainable natural resource management (see box 13).

Box 13: Small scale fisheries governance in southern Kenya

In many of the rural villages along the Kenyan coast a majority of the households depend primarily on fishing for their livelihood while farming and small scale businesses represent some alternative livelihoods. One of these villages has been the focus of a series of studies investigating how social networks, social capital and leadership characteristics among the resource users might affect the way they manage their natural resources. The village in focus is a rural fishing village located along the south coast of Kenya and has approximately 200 households. The ecological system is characterized by mangroves, mudflats and seagrass meadows in the shallow part of the bay. A combination of in-depth interviews, surveys, focus group interviews, and ecological studies, have led to insights on a range of topics pertinent for the management of the local fisheries resources. For example, how informal relational patterns among fishermen have shaped the diverse patterns of knowledge distributions seen in the village. Furthermore, by relating the qualitative data from the in-depth interviews to the management practices currently in use, it is suggested, among other things, that both high level of social capital, as well as the existence of highly motivated key individuals, are needed

to enable a community to collectively devise common rules and regulation for sustainable natural resource management.

Source: Bodin, Ö. and Crona B. (2008) “Community-based management of natural resources – exploring the role of social capital and leadership in a rural fishing community” World Development 36(12).

6.1 Bridging organizations

One possible organizational mechanism to address the steering challenges posed by surprise, and non-linearity, are bridging organizations. These are organizations that serve as a link between other organizations and individuals at multiple levels of societal organization (Hahn et al 2006). These organizations promote a key function in dealing with both slow and rapid change (Folke et al 2005). In the first case, they have the ability to transfer information about scientific advances, pending policy changes and funding, and innovative approaches that reduce vulnerability to actors in the network. At best, these are able to deal with the challenges posed by segmented institutional structures, and improve the capacity of local actors to deal with a range of “misfits” or “disjunctures” between exiting governance modes, and the temporal and spatial dynamics of social, economical and ecological change. Examples here are attempts to bridge mismanagement of natural resources created by the mismatch between administrative borders, and ecosystem boundaries; or initiatives to steer away from single-species management in fisheries to reduce the risk of abrupt and irreversible loss of fish stocks.

For rapid change – such as forest fires, plant disease and invasive alien species - bridging organizations can prove crucial in bringing together information and actors to secure prompt responses. One such example is the response to the droughts and fires in the Amazonia. While the speed and magnitude of the events caught local communities and government organizations with surprise, the 2005 crises was unconventional in its rapid response. This success stems fundamentally by the successful coordination of extensive networks of state and non-state actors – ranging from local governments, national ministries to scientific actors at NASA (cf. Boyd 2008).

In conclusion, rigid command-and-control governance tends to remove mechanisms for creative, adaptive response by people, whereas flexible governance that builds resilience can sustain social-ecological systems in the face of surprise, unpredictability, and complexity.

7 Opportunities for policy and governance

Resilience is increasingly being addressed in a range of policy arenas and key documents. This is true for natural resource related policies, but also for other areas, such as economic and development policies (see introduction, boxes below and the following sections). Successful policies for complex, adaptive social-ecological systems will typically need to be adaptive themselves. That is, they require the ability to cope with, adapt to and shape change without losing options for future development.

In this sense there are a number of opportunities for policy and governance systems that are based on resilience, or, as expressed by Cork et al. (2008): "Resilience is a critical property that allows a country to prosper in a world in which the only certainty is ever increasing rates of change. Resilience provides some insurance for mistakes, allowing a country to explore its possible futures safely".

Unfortunately, there are many examples where policies and management have altered slowly-changing ecological variables, such as hydrology, soils or biodiversity, with disastrous consequences that did not appear until long after the ecosystems were first affected. Similarly, governance can disrupt flexible social institutions and experience or remove mechanisms for creative, adaptive response by people.

Box 14: World Resources Report 2008: Resilience thinking being mainstreamed in the international development community

The report, *World Resources 2008: Roots of Resilience: Growing the Wealth of the Poor,* argues that properly designed ecosystem-based enterprises can create economic, social, and environmental resilience that cushion the impacts of climate change, and deliver continuing benefits to the poor.

Being a joint effort produced by the World Resources Institute, UNEP, UNDP and the World Bank, the report clearly shows that resilience thinking is becoming increasingly mainstreamed in the international development community. The resilience thinking presented in the report builds heavily on the work of scientists associated with the Resilience Alliance and Stockholm Resilience Centre. For instance, *World Resource 2008* refers several times to the report *Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations*, which was commissioned by The Environmental Advisory Council of the Swedish Government for the World Summit on Sustainable Development (WSSD) in Johannesburg, 2002.

In this sense *World Resources 2008* could be regarded as a handbook in modern development cooperation. Instead of focusing on material aid it is emphasising different ways to enhance processes that will give local people the opportunities for creating their own resilient livelihoods and promote sustainable development. Resilience is defined as the capacity of a system to tolerate shocks or disturbances and recover. In human systems, this is closely linked to the adaptive capacity of the system—the ability of individuals and the group to adapt to changing conditions through learning, planning, or reorganization. It is concluded that preventing a social-ecological system under stress from crossing a threshold (i.e. from collapsing to a less desirable state) requires innovation and skills, agreement within the group on what to do, and financial options.

Source: World Resources Institute (WRI) in collaboration with United Nations Development Programme, United Nations Environment Programme, and World Bank. 2008. World Resources 2008: Roots of Resilience—Growing the Wealth of the Poor. Washington, DC: WRI.

Box 15: "Mental tipping point" for Australia's Great Barrier Reef: integrating good science with strong leadership and public understanding

The unconventional management and recent rezoning of Australia's Great Barrier Reef Marine Park has been recognized as a groundbreaking international model for better resilience management of the oceans. Overall, the study shows the importance of a strong leadership and strategies for responding to signals of change before an ecosystem lose too much of its resilience and pass a critical threshold – an insight that has recently been transferred from Australia to Sweden in a consulting process to mobilize new knowledge to tackle the situation in the Baltic Sea.

Researchers from the Stockholm Resilience Centre and the ARC Centre of Excellence for Coral Reef Studies in Australia have identified the keys to the successful ecosystem-based management. They conclude that the Barrier Reef example represents a "mental tipping point" when the earlier perception of a pristine reef turned into a growing awareness of an ecosystem approaching a critical non-return point. This shift in thinking also illustrates a need for a more integrated view of humans and nature, based on active and flexible stewardship of marine ecosystems for human well-being.

Round the world, people are struggling with the difficulties of managing vulnerable coral reef ecosystems in the face of climate change, polluted runoff, overfishing and other human and natural pressures. The problem is that there has been a tendency to relax as soon as some form of governance has been put in place – with the subsequent failure of protection due to human-induced or natural perturbations. The critical realization of the Great Barrier Reef case is that management must rather "expect the unexpected", that is be flexible and adaptive, based on continual scientific monitoring.

One of the most controversial initiatives under the new regime was to extend the area closed to all forms of fishing from 6 to 33 per cent of the total reef area – creating the largest no-take zone in the world. A critical step in the process was to convince local communities that the reef was facing many threats, and to enlist public support for protecting a larger area of the reef and managing it more flexibly. This was accomplished through a major "Reef Under Pressure" community consultation campaign. Backing all of this was the necessary legislation and regulatory powers and also having a sufficient flow of good science to inform the management process constantly. In conclusion, this example shows that laws alone cannot bring about the changes necessary to protect the world's ocean ecosystems – good science and public understanding and support are also vital.

Source: Olsson P, Folke C, Hughes TP. 2008. Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proc Natl Acad Sci USA* 105:9489–9494.

On the contrary, resilience-building governance systems are flexible and open to learning. They attend to slowly-changing, fundamental variables such as experience, memory, and diversity in both social and ecological systems. In order to accomplish this, a diverse decision-making structure is needed, which enables social institutions to better match ecological processes. This implies, for example, that ecosystem management should be shared by subunits of various sizes and scales, from national governments to local communities. Subunits should be allowed to experiment with different kinds of rules, and citizens and officials must have access to local knowledge, and obtain rapid feedback, in order to learn from the experiences of parallel units. With such "polycentric institutions", the failure of one or more of units to respond can lead to small-scale disasters that can be compensated by the successful reaction of other units in the area. (e.g. Ostrom, 1990). This flexibility in management institutions will lead to increased capacity to deal with change in a similar manner as biological diversity tends to increase resilience of ecosystems to external pressures (e.g. Elmqvist et al., 2003).

Box 16: How resilient is Australia? A roundtable drawn from across business, academia and government to prepare Australia for a century of change and challenge

The round table was initiated by the Canberra-based non-profit organisation Australia 21, as a response to two consistent concerns emerging among people around Australia about the future: 1) Australians are not prepared individually or as a nation for future challenges and shocks 2) Rigidity in the social, economic and political systems makes it hard to bring about desirable adaptive change.

The roundtable drawn from across business, academia, and government met in 2007 to consider the importance of a new scientific understanding of resilience to Australia's future. It was concluded that many of the likely external shocks and disturbances that might impact Australia in the coming decades arise from global and regional trends. Among the things Australia needs to be resilient to, according to the roundtable, were: climate change; passing the peak of oil supply; possible pandemics of pests and diseases; collapse of food production in Asia triggered by the failure of the Asian monsoons for several years in a row.

A number of thresholds or tipping points were also identified. Changing beyond these leads to undesirable outcomes that may be difficult or impossible to reverse. They include, for example: major salinity and/or soil acidity problems in response to very wet periods and application of fertilisers; degraded infrastructure, and inappropriate attitudes and policy responses; major social disruptions and deaths due to inability to cope with one or more disease pandemics; and extinction of a number of native species that are at the edges of their environmental tolerances, in response to temperature and water shocks.

The group concluded that the future well-being of Australia depends on its ability to manage the kinds of shocks and non-return points described above — either to avoid crossing them, or to be able to delay or ease the shocks. This ability depends on Australia's adaptive capacity and on how generally resilient the nation's ecological and social systems are.

The group saw the need to introduce "resilience thinking" into the operation of public and corporate policy, e.g. through encouraging diverse ideas, skills, viewpoints and innovation. It recommended increased community discussion of values and purpose and a greater willingness to explore alternative untested ideas from "business as usual". Moreover, the group applauded the tendency for retired members of society investing in ideas and maintaining social connections, and proposed a national assessment of Australia's resilience.

Sources: "Rapid and Surprising Change" and "How Resilient is Australia?", both available at: www.australia21.org.au

Moreover, a resilience approach will focus more on establishing incentives for stewardship of landscapes and seascapes, rather than fragmented policies with emphasis on incentives for specific resources, commonly ignoring their interaction across geographical scales and between sectors. A strong focus on sustaining a stable flow of a particular resource also tends to result in a narrow focus on management and monitoring on variables that may be sub-optimal from a resilience perspective. Hence, understanding and monitoring change in slow variables is critical for sustaining resource flow in the long term. This implies that optimization and "quick-fixes" (see section 8.2) must be replaced by risk spreading and insurance strategies to maintain options in the face of surprise, unpredictability, and complexity. The resilience perspective can also offer some insights on the important role of leadership and vision. Several studies have shown that a strong leadership is critical for guiding social-ecological transitions to ecosystem-based governance regimes (e.g. Olsson et al., 2004).

In the following sections we go through a collection of examples of development strategies/plans in Sweden and Europe, at different scales, identifying things which

are 'good' (enhancing resilience) and 'bad' (reducing resilience of a preferred state or hinder transformation when resilience of a unwanted state is high).

Table 3: The current focus of governance, economics, policy and practice compared with a possible development under a resilience framework.

	Current focus	Possible development under a Resilience framework	
Governance	Optimisation of social-economic output	Redundancy Active pre-cautionary principle	
Economic policy	Growth paradigm based on assumption of incremental change, long-term growth and predictability. No ability of building in impacts (risks, benefits or costs) of abrupt non-linear change. The main indicators used (GDP growth, interest rates, unemployment etc.) are snapshots and give little information about the capacity to sustain wealth.	Introduction of inclusive wealth principles in national accounting, and serious risk analyses of abrupt regime shifts in economic markets under multiple social and ecological drivers (such as population growth, consumption and production trends, and global environmental change)	
Policy	Incentives for resource exploitation	Incentives for landscape stewardship	
Practice	Sustainable development in practice translated to minimizing negative externalities and environmental impacts, within a given development paradigm	Governance and management geared at building institutional and ecosystem diversity. Identify potential regime shifts in both social and ecological systems (e.g., collapse of political trust, flips in lakes and forests). Management of both slow and fast variables (e.g., slow variables such as knowledge and soil fertility, and fast variables such as health care and food supply). Corporate Ecosystem Services Review and managing businesses, communities, cities, as social-ecological systems rather than social systems causing environmental impacts.	

7.1 Resilience Impact analysis: EU-policies

Policies for resilience should stimulate the creation of arenas for flexible collaboration and management of social-ecological systems, with open institutions that allow for learning and building adaptive capacity. In this respect, the EU Water Framework

Directive (2000/60/EC) represents a substantial change in how member states organize their management of water resources. Governance institutions are defined by the geographical boundaries of the ecosystem (drainage basin), rather than the other way around (resource management being defined by the geographical scope of institutions). Moreover, the directive encourages active involvement of all interested parties in its implementation, making room for social learning processes through participatory designs. Target conditions are also set according to the capacity of the ecosystem, as the aim is to achieve good overall quality of European water bodies within 15 yr.

Hence, the Water Framework Directive could be seen as a groundbreaking directive in incorporating resilience thinking in European policies for natural resource management. The practical implementation of the directive varies substantially between member states, but the framework for enabling resilience management of water resources is definitely in place. This is only partially true for a number of relevant directives and policies at the European level (see below).

7.1.1 The Common Agricultural Policy

The commercial agricultural sector world-wide has over the past 50 years evolved towards an extraordinarily productive level, enabling humanity to steer away from risks of mass-starvation e.g., in South and South-East Asia in the 1960s- and 1970s with the 1st Green Revolution. This desirable development has, however, come at two major costs that are increasingly causing concern. First, that the massive improvements in productivity are almost entirely oil dependent, through increased mechanisation and through large increase in use of oil-intensive production of fertilisers. Combined with intensive mono-cropping systems, modern agriculture has become one of the largest emitters of greenhouse gases (contributing with up to 30 % of global emissions according to some estimates). Secondly, that the "development" has been equivalent to a simplification of landscapes. Large monocultures of a few food and fodder crops, has created agricultural systems vulnerable to disturbances such as disease, market fluctuations and climate change. Today, it is increasingly clear that this vulnerable fossil fuel dependent agricultural system is not configured to face the turbulent social-ecological future humanity seems to be heading towards. At the same time, the world population is decisively moving towards 9 billion people, and current malnourishment is stubbornly stuck at approximately 1 billion people. There is a strong consensus that the incentives under the Common Agricultural Policy (CAP) of the European Union, have accentuated a development towards a more vulnerable and unsustainable agricultural sector, e.g. as it has traditionally tended to promote a range of misguided subsidies for steadily accelerating productivity (e.g. through indiscriminate use of fertilizers and pesticides) at the expense of ecosystem services.

Reforms of CAP are currently underway and since the reform work started in 2005 the payment scheme now puts the environment more at the centre of farming policy, with e.g. limits on the amount of commercial fertilisers which can be used in vulnerable areas and a number of basic environmental requirements as a prerequisite to maintain subsidy payments. However, considering the big challenges that the agricultural sector is facing, due to climate change, biodiversity loss, water shortages and soil and water pollution, much more must be done to reform the goals and tools of

the CAP to enable a development that not only promotes sustainable agricultural practices, but also equips European farms and the agricultural sector with the resilience to face disturbances under global environmental change.

Policies and programs based on experiences and principles of resilience and management of ecosystem services has the potential to become pivotal in this respect. They can provide alternatives to decades of commodity-based farm policy, where the consequence has been to reduce diversity and increase vulnerability to external disturbances. Increasingly farmers should be recognised as stewards of the land and water resources and recognised for producing much more than just food and fiber, e.g. reducing risks of climate induced disasters by sustaining biological diversity, sustaining open landscapes, protection from flooding, water purification, maintenance of biological diversity, uptake of greenhouse gases and other ecosystem services. As mentioned earlier the UN Millennium Ecosystem Assessment concluded that 60 % of the planet's ecosystem services are currently overexploited or threatened due to e.g. damage to habitats, invading species, eutrophication and environmental pollutants. The changes in the global climate and other global environmental changes pose additional threats. Industrialised agricultural systems are vulnerable to such pressures, and constitute the main reason behind the degradation of ecosystem services.

In light of this, a growing number of voices – with the over 400 scientists behind The International Assessment of Agricultural Science and Technology for Development (IAASTD) at the forefront – are calling for a radical change in the way the world grows its food. If the world is to cope with a growing population and climate change while avoiding social breakdown and environmental collapse a new form of agriculture based more on local inputs, biological diversity and maintained or improved ecosystem services is needed. Properly designed, this could decrease the need for fossil fuel and also make agriculture less susceptible to climate change.

The UN Food and Agriculture Organisation (FAO) adopts the same theme in the report 'State of Food and Agriculture 2007', which recommends directing payments to farmers for the ecosystem services (PES) they provide. The FAO claims that this could be a good way of protecting the environment and doing something about the growing problems of climate change, declining biological diversity and lack of access to water. The FAO, like the Millennium Ecosystem Assessment, believes that one of the most important reasons for the environmental problems in agriculture is that a number of ecosystem services do not have any direct market value. Farmers therefore actually have no economic incentive to protect ecosystems or to use the services they provide in a sustainable way. Today farmers receive payment for the amount of food, fibre or biofuels they produce, while the value of other ecosystem services that agriculture can produce is underestimated. The FAO suggests that the system of payments for ecosystem services could e.g. comprise direct payments from governments to producers or indirect payments through consumers paying extra for 'ecosystem services- produced' food in the same way that many today show increased willingness to pay for organic and fair-traded products. It is, however, important to recognize that payments for ecosystem services are not originally designed to address equity and fairness, rather the objective is to obtain the most cost effective solution to an environmental problem. It is therefore essential to make sure that any PES does not cause social disruptions by creating inequitable outcomes.

One well-known example of a PES-system in Europe is the water bottling company Vittel in France, which addressed its water contamination problem by paying farmers in the watershed to switch to more sustainable land use practices and restoring the ecosystems surrounding the springs. The strategy worked; water purity returned and Vittel is now one of Nestlé Waters' top selling brands. Practices adopted include adopting extensive cattle ranching, and pasture management (switching from maize to hay and alfalfa), compost animal waste and give up agrochemicals. Farmers receive on average, about 200 Euros/ha/year over five years. Even though bottled water represents a form of consumption that is in many respects not very resilient as it involves huge energy costs (in transportation, bottles, etc) this case is interesting from an ecosystem services perspective.

Table 4: The current focus of the Common Agricultural Policy (CAP) compared with a possible development under a resilience framework.

	Current mode	**Resilience-mode**
Governance	Focus on socio-economic optimisation	Further reforms of CAP to enable sustainable agriculture and equip the sector with resilience to global environmental change
Econ policy	Misguided subsidies for steadily increased productivity with negative side-effects on biodiversity, waterways etc.	Basic environmental requirements a prerequisite to maintain subsidies, and payments schemes for ecosystem services (PES)
Policy	Commodity-based farm policies that reduce diversity and create vulnerability to external disturbance	Policy that recognise farmers as stewards of the land and providers of multiple ecosystem services
Practice	Mono-cropping based on mechanisation and fossil-fuel consuming pesticides and fertilisers	Management for diversity and ecosystem services in order to reduce vulnerability to climate change and reduce the need for fossil fuels

7.1.2 The Common Fisheries Policy (CFP)

It is widely recognized that the Common Fisheries Policy (CFP) has failed to deliver on its goals for social, economical and ecological sustainability. Currently, 80% of European stocks are fished so intensely that the yield is reduced. This compares to the global average of 25%, or 25% in the USA, 40% in Australia and 15% in New Zealand (Commission working document 2008). The gloomy present European situation is due to a lack of capital, as well as self-reinforcing feed back mechanisms between different types of capital deficiencies. Perverse subsidies have resulted in an increase in fishing capacity, and invested revenues have increased fleet efficiency in the absence of a "capacity control"-system. Altogether, there is currently a substantial overcapacity in European fishing fleets: *there is simply more capacity to catch fish than there are fish in the sea.*

This has resulted in strong political pressure from interest groups (fishermen) to maintaining unsustainably high quotas in order to prevent (the too many) fishermen from going bankrupt. In turn, this has depleted fish stocks, leading to a reduced

profitability for fishermen and even more vocal demand for high quotas. When stocks are substantially depleted, official quotas are finally reduced. However, this stimulates an increase in illegal fisheries and high-grading (i.e. throwing poor quality fish overboard to increase value of catch) to maintain profitability, leading to a decrease in quality of input data. Fish stock assessments are to a large extent based on fishing mortality (how large proportion of the stock is being caught). However, if catches are not officially reported, assessment quality will be reduced. Poor assessments will be criticized by fishermen organizations, leading to increased possibilities to make unsustainable decisions on catch quotas. Unsustainable quotas, poor assessment and vocal criticism from fishermen will result in a lack of trust (social capital) between fishermen, scientists and politicians. Profitability will be further reduced as stocks continue to decrease. In addition, the economic impacts from reduced stocks have been recently exacerbated due to increased fuel costs, further reducing profitability.

Box 17: Promising Baltic cod increase, but more is needed to safeguard the resilience of stocks to future climate changes

The eastern Baltic cod stock has increased since 2005 and is now higher than ever during the last decade, according to the International Council for the Exploration of the Seas (ICES). Research at the Department of Systems Ecology and the Baltic Nest Institute at Stockholm Resilience Centre has analysed whether this increase is a result of management reducing the fishing pressure or improved environmental conditions resulting in higher reproduction. Model simulations show that neither reduced catches alone, nor higher reproduction, could explain the increase. Each factor only explained 25 percent of the total increase. Synergies between both factors were necessary for the current increase in the Baltic Sea cod stock. This analysis clearly illustrates the importance of management actions but it also underlines the interactive dynamics in nature and the challenges involved in ecosystem management.

This does, however, not mean that the Baltic cod stock is now safe. A similar increase of the cod stock in the early 1990’s was rapidly nullified by unsustainable catches. Nonetheless, we are now in a window of opportunity to re-build the cod stock. If only the management plan decided in 2007 is followed and illegal catches are controlled, the future of the Baltic cod looks better than it has for a long time, according to the researchers. This is crucial as research on cod in other seas has underlined the importance of high stock levels for its capacity to cope with environmental change. Hence, cod stocks should be allowed to increase more – before catch quotas are increased – in order to become resilient enough to meet the increasing challenges from the ongoing climate change that is projected to lead to worsening environmental conditions for cod in the future (e.g. through decreased salinity as an effect of increased precipitation and run off from land).

Source: The study is a work in progress at Stockholm University (the Department of Systems Ecology, the Baltic Nest Institute at Stockholm Resilience Centre). http://www.stockholmresilience.org/research/researchnews/balticcodincreaseinstock.5.87749a811cbd4c4fb4800012907.html

In contrast, a CFP with resilience at its core takes its starting point in the ecological capacity to produce fish and understands that social and economic goals only can be achieved if this natural capital is prioritized. Enforceable harvest control rules, incentives for fishermen and understanding marine ecosystem dynamics are critical components for a resilient CFP, using an ecosystem approach. Fortunately, a CFP revision process will begin during 2009, with an expected revised CFP decided on in 2012. Hopefully, the present crisis in the European fishing sector could stimulate transformative capacity and open up new opportunities to steer towards a flexible,

regionalized policy with participating stakeholders who can be part of the solutions, rather than part of the problem.

Table 5: The current focus of the Common Fisheries Policy compared with a possible development under a resilience framework.

	Current mode	Resilience-mode
Governance	Regional Advisory Councils (RAC) are consulted	Mandate and responsibility regionalized to RACs
Econ policy	Inefficient use of fleet capacity, poor profitability, social unrest due to low quotas and high fuel costs, eroded natural capital	Capacity of natural capital starting point for developing efficient fleet capacity and high profitability
Policy	Lack of priorities between conflicting goals, micromanagement	A clear priority: natural capital first, economic and social sustainability will follow
Practice	Practical political decisions bordering the arbitrary. Lack of trust erodes potential for sustainability.	Long-term decision rules decoupled from politics. Incentive structures for fishermen to be “stewards of the seascape”

7.1.3 The Marine Strategy Directive

The EU Marine Strategy Directive was decided by the Council of Ministers on June 17, 2008. The aim of the directive is to take a holistic approach to address all human activities that have an impact on the marine environment. The directive is unique in its strong focus on maintaining biodiversity and sustaining clean, healthy and productive seas. The focus of the directive is on the sustainable use of goods and services, with a special emphasis on resilience. It is also unique as it ambitiously tries to integrate concerns from other policy areas. Its overarching framework binds Member States to action and there is a firm timetable, but implementation is regional, using existing bodies of governance. Another key aspect is that the starting point is the ecosystems, and that spatial protection measures are underlined. All this renders the directive very “knowledge-intensive”, requiring region-specific programs of measures including assessments of pressures and impacts on the ecosystem, as well as economic and social analyses of resource use and of the cost of degradation of the marine environment. The aim is to accomplish a defined good environmental status. Besides the obvious difficulties in defining such status in dynamic ecosystems, the directive has the potential to be a leading policy instrument for integrating resilience in European natural resource management. However, the success of implementation is to a large extent defined by policy on “the next level”, i.e. the future European Maritime Policy.

Table 6: The current focus of the Marine Strategy Directive compared with a possible development under a resilience framework.

	Current mode	Resilience-mode
Governance	Capacity for regional environmental governance structures to implement policies in multiple sectors	As current

Econ policy	Costs of actions (and inaction) early phase of policy implementation framework	As current
Policy	General goals, regional implementation, focus is on ecosystem structure, function and resilience	As current
Practice	As yet to develop. Status in relation to Maritime policy key for success	

7.1.4 Climate politics

Future policies within the EU and the rest of the world must address climate change within the wider challenge of preserving the capacity of global ecosystems to continue to function as sinks for greenhouse gases, and avoid ecosystem feedbacks that accelerate global warming (see summary table below). Future greenhouse gas emission reduction targets and other policy measures within the EU must reflect the most current, authoritative and independent science. Action for mitigating climate change must be based on a risk-management approach that steers away from the risk of planetary tipping points. Moreover, ethics and equity must lie at the core of the global response to climate change. Without a focus on global equity, the response will be only partial and inadequate.

However, the ultimate effectiveness of all future climate agreements depends on global governance reform that addresses the policy and market failures that produce environmental degradation, such as climate change. Managing emissions alone will not be sufficient. Active stewardship of the Earth's ecosystems, together with massive support for resilience-building, adaptation, and economic and social transformation in the face of substantial unavoidable climate change will be required.

Table 7: The current focus of EU climate politics compared with a possible development under a resilience framework.

	Current framework	**Applying a Resilience framework**
Governance	Mitigation targets and trajectories that (i) do not consider tipping points and multiple stable states in the Earth system, and (ii) a sectoral approach that does not consider the sink and source risks related to terrestrial and aquatic ecosystems (e.g., that land and oceans currently function as a sink of ~50 % of human CO_2 emissions). Mitigation and adaptation strategies that to only a limited extent considers management of ecosystems.	Mitigation targets that take a more serious risk approach to tipping points in the Earth system. Fully integrate governance and land and oceans, aquatic and terrestrial ecosystems in mitigating climate change. Fully integrate ecosystem management as a key to climate adaptation.

Econ policy	Incremental change and pursuit of a few universal economic policy measures (such a cap-and-trade). Fear of leading the way in economic policy terms, in order to avoid undermining short-term market competitiveness (potentially at the expense of long-term strength).	Allow for consideration of transformative economic policies (e.g., major shifts in tax incentives, market caps, and trade policies). Allow for policy experimentation and learning.
Policy	Policy measures remain embedded in the social and economic growth model that generated the problems of human induced climate change. Incremental change within this model remains the key focus (e.g., difficulty in introducing stronger policies on sustainable transport) Climate impacts taken seriously at local level, but difficulty to consider regional and global impacts (e.g., in migration)	Ability to consider innovations in policy to allow for transformative change away from unsustainable social trajectories. Addressing climate impacts and adaptation strategies from a multi-scale perspective (local, national, regional and global) Key to consider multiple policy areas and their interactions (e.g., agriculture, industry, trade and health, and how these interact to raise, reduce resilience).
Practice	Minimising climate impacts from current social-economic development setting. Under current financial crisis < 10 % of new funding in stimulus package of governments in the EU for measures that mitigate climate change.	Investments in industry and sectors across societies that stimulate a transformation towards a low-carbon economy.

7.1.5 The Lisbon Strategy

The Lisbon Strategy[1] aims at modernizing Europe and making it the most competitive region in the world. It focuses on increasing economic growth and employment, within a framework of sustainable development. This in turn is generally interpreted as decoupling (continued economic growth while reducing pollution and other negative environmental impacts). For example, in its Broad Economic Policy Guidelines (BEPGs) for the Lisbon Strategy 2003-2005, the European Commission declared that: “Growth will only be sustainable if action is taken now to cater for the long term impact of economic, environmental and social factors.”[2] Economic growth must thus not be achieved at the expense of the environment. Member States should

[1] http://ec.europa.eu/growthandjobs/index_en.htm
[2] http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/03/188&format=HTML&aged=0&language=EN&guiLanguage=en

reduce subsidies, tax exemptions and other incentives that have a negative environmental impact.

Vulnerability to climate change and other environmental risks are acknowledged and justifies modification in the conventional economic policies for growth and employment. Eco-technology is emphasized but otherwise the content or quality of economic activities is not questioned. Resilience is often mentioned in relation to stable public finances and sustainable growth.[3] In February 2008, José Manuel Durão Barroso, President of the European Commission, commented on the current turbulence in the financial markets but concluded that "The resilience of the European economy is due in part to the strength of the euro and the discipline associated with the single currency, but also to the economic reforms introduced by the renewed Lisbon Strategy, which are making our economies increasingly strong."[4]

In March 2008, the 27 heads of State and Government reaffirmed their commitment to the Lisbon Strategy endorsing the new three-year cycle of the Strategy for growth and jobs, covering the period 2008-2010. According to Joaquín Almunia, European Commissioner for Economic and Monetary Policy, the new cycle begins just as we enter more difficult economic times, when structural reforms become even more important to improve the ***resilience*** of our economy to shocks.[5]

Sustainable development and resilience within the Lisbon Strategy follows a conventional approach and focuses on increasing economic growth and employment with the aim to achieve social, financial and environmental sustainability and "resilience," which is more or less only interpreted as persistence following shocks, neglecting the other two aspects of resilience: adaptability and transformability.

Towards a resilience approach?

A recent report (Facing The Challenge, the Lisbon Strategy for growth and employment) by a group of independent experts under the chairmanship of former Dutch Prime Minister Wim Kok, underlines how the environment can be a source of competitive advantage for Europe and that integrating environment into wider decision-making is essential for the success of the Lisbon Strategy: "Well thought-out environmental policies provide opportunities for innovation, create new markets, and increase competitiveness through greater resource efficiency and new investment opportunities. In this sense, environment policies can help achieve the core Lisbon Strategy objectives of more growth and jobs," the report notes.[6]

In the above-mentioned report, strategies for growth and jobs start with knowledge about ecosystems and examine how avoiding threats or realising business opportunities in relation to environmental change can be a source of competitive advantage. Knowledge on conventional policy tools like economic incentives are important but the focus is not merely to reduce pollution but to improve the functions

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[3]http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/147&format=HTML&aged=0&language=EN&guiLanguage=en
[4]http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/112&format=HTML&aged=0&language=EN&guiLanguage=en
[5]http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/147&format=HTML&aged=0&language=EN&guiLanguage=en
[6] http://ec.europa.eu/environment/news/efe/19/article_2098_en.htm#top

of ecosystems and thereby the production of various ecosystem services that are important to human well-being. Hence, the largest difference between the perspective of the Lisbon Strategy and the Wim Kok-report is the starting point: strategies for increasing economic growth or strategies for enhancing ecosystem services, see Figure below.

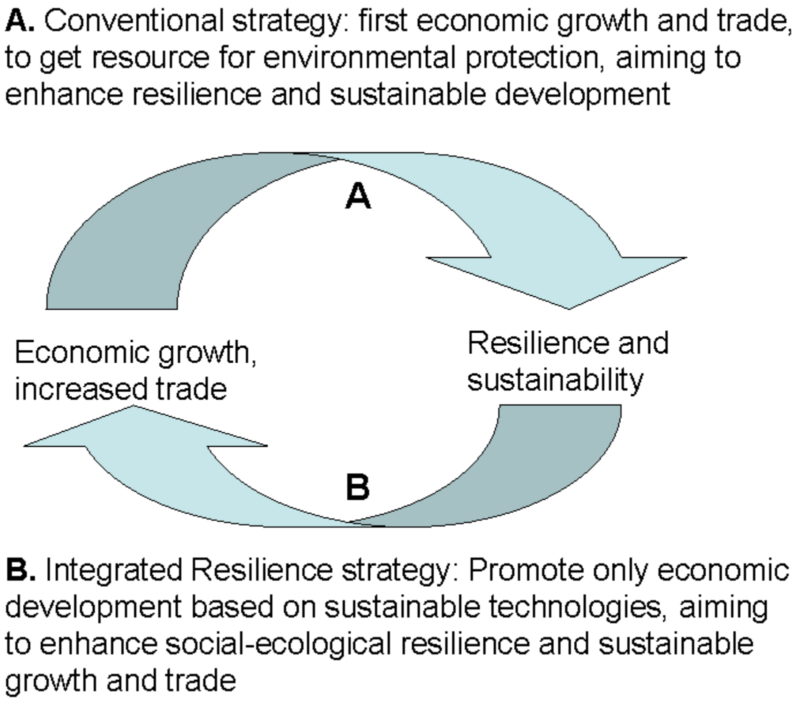

Fig 11: Comparison of the conventional strategy and an integrated resilience strategy that promotes economic development based on sustainable technologies.

Another difference is that the resilience approach has an integrated perspective on how economic, financial, social and environmental sustainability are interrelated, and that well-functioning ecosystems are the foundation of human well-being. It acknowledges that a crisis in one policy area can quickly spread to other policy areas (Duit & Galaz, 2008). Indeed, this is in part acknowledged by Joaquín Almunia, European Commissioner for Economic and Monetary Policy: "Indeed, the substantial changes in relative prices, caused by climate change and tension on natural resource markets, are likely to present a stiff challenge for most EU countries. We may be coming to the end of the period of 'great moderation', which has assured us growth and stability for over 20 years. If so, this would make supporting economic growth while maintaining price stability a much more demanding task in the years to come. These trends will become more and more relevant in the future and we will need to be well prepared to deal with the economic challenges they bring."[7]

[7]http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/147&format=HTML&aged=0&language=EN&guiLanguage=en

Still, Joaquín Almunia does not call for an integrated structural reform, starting from an understanding of ecosystem dynamics, how close we are critical thresholds and which ecosystem services are most vulnerable. Instead he illustrates the conventional partial analysis: "Structural reforms make our economies more flexible and resilient by increasing potential growth and improving our capacity to adjust to changing economic conditions. They are among the best tools we have to weather the current storm."

7.2 Resilience, optimization and "quick fixes"

Policy for resilience should stimulate the development of indicators of gradual change and early warning signals of loss of resilience and possible threshold effects. Often these aspects are given little regard, resulting in a simplified understanding of systems, and a strong focus on optimization and "quick fixes" (Sterner et al., 2006). Optimization have little use in systems which exhibit non-linear dynamics, and will have to be replaced by risk spreading and insurance strategies to maintain options and sustain social-ecological systems in the face of surprise, unpredictability, and complexity (see also sections 5.2-5.5). Quick fixes can be part of the solutions, but may also contribute to increased problems. Quick fixes are generally used within a range of policy areas, but recently, there has been an increased discussion about large-scale experiments designed to either (1) revert systems back to more favourable regimes or (2) to increase capacity of ecosystems to function as carbon sinks.

These experiments include proposals to alter weather and storm patterns as well as modification of the atmosphere through the creation of shields of either sulphur or metal nanoparticles to reflect incoming sunlight. From a resilience point of view, the presently proposed large-scale geo-engineering schemes seem unacceptably risky – even though the time may well come when they are accepted as less risky than doing nothing (Launder, 2008). Notwithstanding, many problems, like the food price crisis, hurricane Katrina and the avian flu, do require quick-fixes to minimize immediate suffering, but the basic message of the resilience thinkers is that these kind of problems are often caused, in the first place, by the gradual effects of previous short-sighted policies. Hence, instead of spending money only on quick fixes they argue that politicians must dare bearing the political costs of more fundamental solutions (Sterner et al., 2006) . In the case of New Orleans, where thoughtless management led to the 2005 flood catastrophe, they suggest restoring the river to its natural course and rebuilding the floodplains and delta that once gave the city protection. This strategy is based on the notion that working with instead of against nature by restoring ecosystem services is better in the long run. Similar choices between quick fixes and more resilient solutions exist for a number of other current environmental problems.

All in all, resilience research and approaches are essential to understand implications and risks of geo-engineering/quick-fix approaches and help prevent the creation of new, global problems that may even be on par with the problem they are supposed to help solve.

7.2.1 Fishing for a regime shift?

The Baltic Sea ecosystem has been substantially affected by overfishing of cod, eutrophication and other human impacts. There are indications that a recovery of the

cod stock may be hampered by predation from their prey (sprat), which consume cod eggs and may compete with cod larvae for their zooplankton prey. As a consequence, the National Board of Fisheries has been commissioned by the Swedish government to conduct a large-scale experiment including a geographical concentration of fishing effort for sprat. The experiment was originally intended as a large-scale management approach to revert the ecosystem back to a cod dominated state, but the understanding of the ecosystem dynamics is not at a state where scientists can say whether or not these results will be achieved. The ambition of the National Board of Fisheries has instead been adjusted to a level where the experiment is intended more as a mean to understand the ecosystem than to solve the problem and help the cod stocks to recover. Other, and substantially larger scale experiments, however, have substantially higher ambitions.

7.2.2 Forest fertilization

Temperate and boreal forest ecosystems contain a large part of the carbon stored on land mainly in the form of soil organic matter (SOM), but also as biomass. Several studies (e.g. Lai et al 2002) have shown that nitrogen (N) fertilization could increases carbon sequestration and large-scale fertilization of boreal forest would increase carbon uptake substantially, assuming that carbon sequestration is a linear process. However, internal feedback mechanisms (respiration, photosynthesis and nutrient balance), may suddenly transform the forest ecosystem from a carbon sink to a carbon source. The same results can be expected from external shocks like storms and pests/diseases because intensive fertilization of forests is likely to increase vulnerability ((Lindroth et al. 2009). "The Tansley review", financed by the Swedish Energy Agency and the Swedish University of Agricultural Sciences through the programme Carbon Sweden, noted that "most fertilization studies on N-limited sites show that increasing nutrient availability does not increase fine-root biomass, and may decrease the number of mycorrhizal root tips as well as the production of mycorrhizal mycelium in the soil" (Hyvönen et al 2007). This is crucial as these root and soil variables might be the long-term determinants (slow variables) of resilience of forest ecosystems as well as determining the long-term capacity of carbon sequestration. Carbon sequestration on land is a part of the planets' self-organisation capacity, but projections of the possibilities to influence this capacity by intensive fertilization are currently highly uncertain, although they appear to present an attractive measure (Magnani and others 2007).

Moreover, inefficient use of the applied N by the plants might lead to the formation of nitrous oxide (N_2O), which is about 300 times more potent as greenhouse gas than carbon dioxide. If this is the case, the enhanced carbon uptake is offset by the production of another greenhouse gas. Until the trade-off between C sequestration and N_2O release in forest ecosystems is quantified, N fertilization should be treated with caution. Another aspect to consider is that increased N input has been shown to induce substantial changes in the composition and biodiversity of boreal forests (Nordin et al., 2005).

7.2.3 Ocean fertilization

In spring 2008, the conference of the parties (COP) to the Convention on Biological Diversity agreed on a moratorium on 'ocean fertilization' as a measure to tackle climate change. Planktos Inc. (a US based corporation), had planned to dump many

hundreds of tons of iron nanoparticles over an area of 10 000 km^2 close to the Galapagos Islands, with the intention to spur massive growth – a bloom – of plankton (iron is a limiting nutrient in most ocean ecosystems). The CO_2 uptake of the plankton (and assumed eventual sedimentation at the bottom of the sea) was in turn assumed to generate carbon credits for the carbon trading market. Action by civil society organizations and strong statements by the intergovernmental scientific committees of the London Convention and London Protocol on ocean dumping stopped the plans (ETC Group 2007a), referring to potential negative impacts on the marine environment and human health the limited knowledge about the effectiveness of ocean iron fertilization (The International Maritime Organization, 2007). Whether or not iron fertilization would really be a significant and lasting sequestration of carbon is currently unknown.

However, since 1993 at least ten ocean fertilization experiments have taken place involving at least nine different countries (ETC Group, 2007b). Commercial interests are investing in the approach and despite the de facto moratorium agreed with all parties to the Convention on Biological Diversity, CBD, researchers in January 2009 on board the German vessel RV Polarstern dumped six tons of iron sulphate over 300 square kilometres of open ocean in the Scotia Sea (east of Argentina) to artificially prompt the growth of a large plankton bloom.

8 Concluding remarks and key messages

Resilience thinking is increasingly influencing governance and management of the financial, environmental and social challenges facing the global community. This is encouraging. For too long we have assumed that nature is separate from society, when in fact ecosystems provide the basis for social and economic progress and stability. For too long we have assumed that nature changes in slow, linear and predictable ways, when in fact many systems are characterized by long periods of small change followed by rapid and large changes when they are pushed across critical tipping points. Resilience provides social and ecological systems with the ability to withstand disturbance and shocks without shifting from desired to undesired states. When resilience is lost, e.g. under the pressure from human emission of greenhouse gases combined with land degradation, even a small trigger – such as an economic downturn, drought or storm – can tip a society or an ecosystem into a negative trajectory.

The science of resilience focuses on the ability to develop in the face of growing turbulence through persistence, adaptation and the ability to innovate and transform when adaptation is no longer an option. A growing scientific understanding of resilience is now occurring at the same time that political leaders are becoming increasingly concerned about our societies' ability to cope with a number of looming global and regional threats, including climate change, market collapses, peak oil, pandemics, ocean acidification, collapsing fisheries, water scarcity and terrorist activity, to name a few.

The Australian government has applied resilience thinking in its effort to manage the Great Barrier Reef, as a way to preserve this unique collection of coral reefs in the face of multiple shocks from climate change, eutrophication and heavy pressures from

the tourist industry. Furthermore, the Australia21 group, based on real experiences of growing frequency of climate induced shocks (droughts and fires), has taken the initiative to gather key stakeholders to formulate a resilience strategy for the nation. Likewise, the global climate adaptation agenda is increasingly framed in terms of building resilience, which changes focus from gradually coping under the pressure of a changing climate to investments in development that protects against climate risks and enables societies to adapt and transform. The World Bank's Pilot Program for Climate Resilience (PPCR) is one such example. Resilience thinking changes the focus on climate change mitigation and adaptation, from a mitigation focus on dealing with emissions of greenhouse gases (GHG) to an active stewardship of oceans and land ecosystems. Adaptation efforts are broadened from an engineering focus to active management of forests, watersheds, biodiversity, land and coastal system to reduce impacts of climate change.

Resilience building in the face of climate change also has profound impacts on efforts of poverty alleviation, as shown in the latest World Resources Report *"World Resources 2008: Roots of Resilience: Growing the Wealth of the Poor"* by the World Resources Institute, which focused on resilience "for cushioning the impacts of climate change and delivering continuing benefits to the poor". Operationalising resilience in development efforts thus means moving away from seeing biodiversity as a conservation challenge and environmental issues as a matter of minimizing human impacts. It is rather about viewing ecosystems as the source of human well-being and finding a vast toolbox to provide societies and humanity as a whole with the capacity to continue to develop in an increasingly turbulent world.

In summary this report's overall conclusions and policy implications regarding the role of resilience for sustainable development can be boiled down into the following 10 key messages:

1. **Social and ecological systems are tightly inter-connected**
Economic and social progress rests on a healthy environment, from local ecosystems to the biosphere as a whole. Maintaining the resilience of ecosystems is not only a question of saving the environment – it is about securing human development. Sustained and enhanced resilience of ecological systems supports both adaptation to and mitigation of climate change. Failing to understand the interconnectedness between ecosystem resilience and human well being, as well as between climate change and ecosystem resilience, is a root cause of both ecosystem degradation and failures to meet socio-economic development goals.

2. **Limits, thresholds and cross-scale effects characterize all systems**
Social-ecological systems have non-linear dynamics. As a consequence they have limits to how much they can be disturbed (changed) and still recover. If these limits (thresholds) are exceeded the system functions differently and develops along a different trajectory. Despite growing evidence that surprise, abrupt change, thresholds and regime shifts constitute normality in ecosystems and social-ecological systems, we still govern and manage forests, water resources, agricultural land and other natural resources as if they follow linear, predictable, and thereby controllable pathways. From this also follows that it is impossible to understand or manage a social-ecological system by focusing merely on one scale.

All systems function at multiple scales and what happens to the system at one scale affects the dynamics at other scales.

3. Mis-matches in social and ecological system scales cause unwanted outcomes

Social and ecological systems operate at different scales in time and space (e.g. when administrative boundaries do not match hydrological boundaries), and the mis-match in these scales is a major cause of unwanted outcomes in managing these strongly interconnected systems. Institutions and policy prescriptions that fail to adapt to these discrepancies run the risk of ending up with ill-founded advice that fails to tackle such emerging global problems as the loss of biological diversity, the degradation of forests and the overarching issue of climate change.

4. Periods of gradual and abrupt change are essential for long-term development of human wellbeing

Social-ecological systems tend to exhibit long periods of gradual, mostly predictable change, during which capital accumulates, that are interspersed by phases of rapid, chaotic change when relationships break apart, capital is lost, and new things can happen. Both phases are essential for long-term development of human wellbeing.

5. Resilience thinking provides a basis for understanding drastic and surprising social and ecological change to avoid deep crises

As a consequence of the preceding observations, resilience is defined as the capacity of a social-ecological system to absorb disturbance, re-organise, and retain essentially the same structure and function. Resilience thinking provides a basis for understanding drastic and surprising social and ecological change, governance to avoid crises, and the sources of innovation for recovery or transformation after a crisis.

6. Expect the unexpected: we need both specific and general resilience

Making a social-ecological system very resilient in some particular way (the resilience "of something, to something") can inadvertently lead to it losing resilience in other ways. Resilience policy and management, therefore, needs to address both specified resilience (dealing with known or suspected thresholds) and general resilience. General resilience is determined by such attributes as diversity (natural and social), tightness of feedbacks, modularity (i.e., avoiding over-connectedness and too much homogeneity), openness, reserves, and overlapping functions. Managing for general resilience of ecological systems would be equivalent to living by the precautionary approach (e.g. following scientific advice for fish stocks). General social-ecological resilience relates to institutional flexibility and an overall capacity to respond to, and deal with change.

7. Biological diversity is increasingly important in light of climate change

Biological diversity plays a crucial role in sustaining the flow of goods and services from ecosystems to society. It spreads risks, provides insurance and makes it possible for ecosystems to reorganise after disturbance. Ecosystems seem to be particularly resilient if there are many species performing the same essential function (such as photosynthesis or pollination) and if species within such 'functional groups' respond in different ways to disturbances, a property known as

'response diversity'. Hence, a rich biodiversity is crucial for the future capacity to adapt to climate change. Measures taken to support both adaptation to and mitigation of climate change should therefore include the sustaining of biodiversity and ecosystem services as an important starting point.

8. A resilience approach sheds new light on future technologies
A resilience approach is essential to understanding both the potential and risks of new technologies, including geo-engineering/quick-fix approaches to climate change. It will help prevent detrimental 'quick-fixes' and avoid the creation of new global problems that could be on par with the problems they are supposed to solve.

9. Declining resilience of natural capital is a growing threat to future wealth
We are facing a historic juncture in which the limits to increased wealth are not the lack of conventional forms of capital assets, but the dwindling resilience of natural capital (the degradation of biological diversity and ecosystem services already today present significant threats to achieving the Millennium Development Goals, according to UN's Millennium Ecosystem Assessment).

10. Resilience thinking can strengthen policymaking in an increasingly complex and turbulent world
As in much of the world today, the big question facing Sweden, and the Nordic region, is: In which parts (areas, enterprises, sectors) should we be trying to enhance resilience, and in which parts should we be promoting transformational change? If a social-ecological system has crossed an irreversible threshold into an undesirable state, or such a shift is inevitable, then trying to enhance resilience amounts to digging the hole deeper, and the appropriate response is transformation into a different kind of system – new key variables, new ways of making a living. There are many examples of regions caught in ecological-economic-social traps, such as desertification-poverty traps. Stemming from these insights we conclude that policy for resilience should:

- Stimulate the development of indicators of gradual change and early warning signals of loss of ecological resilience and possible threshold effects.
- Provide incentives that encourage learning and build ecological knowledge into institutional structures in multi-level governance.
- Be based on the fact that managing the resilience of natural capital is no longer an environmental issue, but rather a development and human wellbeing issue.
- Bridge the gap between scientific knowledge (about biodiversity, resilience and ecosystem services) and policymaking (from local, national to global level). In this context, Sweden should actively support the process to create a global platform or panel for resilient ecosystem services (similar to the IPCC): the intergovernmental science-policy platform on biodiversity and ecosystem services (IPBES).
- Stimulate the business community to integrate resilience thinking and ecosystem services, e.g. through the Corporate Ecosystem Services Review (ESR) developed by the World Resources Institute.

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(Please note that some of the cited literature is only listed in the boxes embedded in the main text).

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