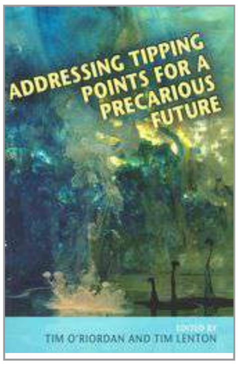

Addressing Tipping Points for a Precarious Future

Timothy O'Riordan and Timothy Lenton

Print publication date: 2013
Print ISBN-13: 9780197265536
Published to British Academy Scholarship Online: January 2014
DOI: 10.5871/bacad/9780197265536.001.0001

Human Resilience in the Face of Biodiversity Tipping Points at Local and Regional Scales

Patricia Howard

DOI:10.5871/bacad/9780197265536.003.0006

[-] Abstract and Keywords

Biodiversity and cultural diversity are intertwined. The threats to biodiversity are already observable and are accelerating. The spread of non-native species is an under-examined threat to biodiversity and to food production. Biodiversity tipping points may most likely appear at the regional scale, as in the drying of the Amazon. The failure of ecosystem integrity and inherent resilience offers a further threat, and the reaction of humans to all of these challenges adds fuel to the fire. Over one-third of the whole population depends on biodiversity — and help to maintain it. Yet part of this vital group is being displaced, losing their cultural integrity, and their language. The tipping points of biodiversity loss are also tipping points of cultural distinctiveness loss.

Keywords: biodiversity, cultural diversity, tipping points, species losses, alien species, human resilience, language disappearance

Perspective

Biodiversity, in its broadest sense, is life on Earth. It has been characterized as a ‘concept, a measurable entity, and a social or political construct’ (Jax 2010). In this last sense, biodiversity is charged with great religious, aesthetic, moral, and economic meanings that vary according to the observer. For ecologists, the broad definition includes genetic diversity, species diversity, and ecosystem diversity, whereas a common narrower definition is the diversity of species (on Earth, in biomes, in ecosystems). Its relevance for biologists and ecologists is usually cast in evolutionary terms or in terms of ecosystem functioning, which some economists refer to as ecosystem services. Ecosystem services are defined as the benefits that humans derive from ecosystem functions or processes. Thus, the relationship between biodiversity change, ecosystem functioning, and ecosystem services has become central to contemporary scientific understanding of biodiversity and human well-being, as well as to a multitude of policies that seek to assess and address human well-being, environmental degradation, and global environmental change. There is great debate and uncertainty about the relations between biodiversity and ecosystem functioning, about the significance of change in biodiversity for ecosystem **(p.105)** functioning, and indeed for evolution. This necessarily creates much uncertainty about the nature of the relationship between biodiversity and human well-being. In spite of such uncertainty, which affects all assessments of the actual and potential threats to human well-being from biodiversity change, there is broad agreement that the implications of current and projected levels of biodiversity change for human well-being are, in most instances, major and possibly dire, at local, regional, and global scales.

Most people across the globe will feel the direct impacts of local biodiversity change, but everyone is likely to feel the indirect impacts, since local changes can connect to create global repercussions. One set of such impacts arises from the rapid emergence and transmission of new infectious diseases and pests that threaten plants and animals (and thus the humans that depend upon them), as well as humans (see e.g. Chivian and Bernstein 2008; Pongsiri 2009; Keesing *et al*. 2010). A second set is presented by 'biodiversity tipping points' that may emerge at regional scale, such as the loss of the Amazon rainforest or the collapse of coral reefs, that will have extra-regional or even global repercussions not only due to the loss of species and ecosystems, but also due to the loss of ecosystem services that these provide at higher scales. A third set of impacts results from the reconfiguration of ecosystems (including tipping into alternative ecosystem states) resulting from changes in species range, phenology, and abundance, which in turn provoke changes in ecosystem functions and associated human benefits. It also includes the loss of single species in particular contexts, such as 'cultural keystone' species or ecological keystone, engineer, or framework species. An example is the threat posed by the loss of functional groups of species, such as pollinators (see e.g. Potts *et al*. 2010), which has major implications for ecosystem productivity and the provision of benefits such as food, fibre, and fuels. A fourth set of direct and indirect impacts arises from human maladaptation to any of these threats.

To adapt successfully to biodiversity tipping points requires major changes in values, priorities, and institutions, particularly economic institutions. Some of this change may be forthcoming but much is unlikely to happen quickly or profoundly enough. A first step is to recognize the implications of biodiversity change and potential tipping points for human welfare. A second is to take urgent measures to mitigate such change, and a third is to consider potential responses to early warnings. This chapter focuses on the first and the third of these options, principally in relation to societies that are directly and highly dependent on biodiversity, since it is **(p.106)** these populations that are (a) most immediately vulnerable to such change, and (b) most important to preserving both the planet's biodiversity and humanity's adaptive capacity.

Types, magnitudes and drivers of biodiversity change

We find ourselves in a period when rates of species extinctions could range between 50 and 500 times background losses, which is the highest rate in the past 65 million years. The effects have been summarized as:

> Changes in species' geographic ranges, genetic risks of extinction, genetic assimilation, natural selection, mutation rates, the shortening of food chains, the increase in nutrient-enriched niches permitting the ascendancy of microbes, and the differential survival of ecological generalists. Rates of evolutionary processes will change in different groups, and speciation in the larger vertebrates is essentially over … Whether the biota will continue to provide the dependable ecological services humans take for granted is less clear … Our

inability to make clearer predictions about the future of evolution has serious consequences for both biodiversity and humanity.

(Woodruff 2001: 5471)

The consequences for biodiversity and humanity depend in part on the timescale. Some scientists argue that the Earth's sixth extinction has already arrived, where an estimated loss of over 75 per cent of species can be expected, possibly within 250 to 500 years (Barnosky *et al*. 2011). Others highlight the fact that projections of species extinction rates are controversial (Pereira *et al*. 2010). A mass extinction hardly bodes well for humans, given the changes in the biosphere, in biomes and ecosystems, the associated pest and disease outbreaks, etc. that are associated with the different drivers of biodiversity change, and the possible critical thresholds or tipping points discussed below and in other chapters presented here. Thus, the implications of what is laid out below are magnified manyfold and their effects become increasingly synergistic over time – 500 years is a very short period when we consider that *Homininae* appeared 8 million years ago, *Homo sapiens* 500,000 years ago, and modern humans 200,000 years ago. Were humans to have a council of elders to deliberate the impact of our activities on future generations, they would certainly be extraordinarily alarmed and calling for radical transformations, as, indeed, are many scientists today.

(p.107) What is extraordinary about this possible sixth extinction of species is that, for the first time in the Earth's history, a species is actually in a position to change the course of evolution writ large (Western 2001; Pereira *et al*. 2010). This is reflected in the wide range of projected changes in biodiversity, because 'there are major opportunities to intervene through better policies, but also because of large uncertainties in projections' (Pereira *et al*. 2010: 1496).

The causes of species extinctions and related changes in biodiversity and ecosystem services can be characterized as synergistic stressors – climatic change coupled with 'abnormally high ecological stressors' and 'unusual interactions' (e.g. between human-induced climate change, habitat fragmentation, pollution, overharvesting, invasive species, pathogens and, some would add, the 'expanding human biomass' (Barnosky *et al*. 2011), although one could just as easily add 'expanding livestock biomass' or 'expanding biofuels production' (Steinfeld *et al*. 2010; Wise *et al*. 2009)). Beyond this, humans have had a massive impact on the productivity, composition, and diversity of terrestrial ecosystems by changing the rates of supply of major nutrients (nitrogen, phosphorus, and atmospheric CO_2), altering regional fire frequencies, and relaxing biogeographic barriers to species dispersal (Tilman and Lehman 2001). Many human-dominated ecosystems are characterized by high natural resource extraction, short food chains, food web simplification, habitat and landscape homogeneity, heavy use of petrochemicals and fossil fuels, convergent soil characteristics, modified hydrological cycles, reduced biotic and physical disturbance regimes, and global mobility of people, goods, and services (Western 2001).

A great concern to biologists and ecologists is the uneven ability of species to change their range, or distributions, in response to climate change (CBD 2007). If individual species are not able to change their range, they are likely to be lost (Root and Hughes 2005; Malcolm *et al*. 2005). It also highlights a second major concern, which is the break-up of species associations and communities, which will result in further extinctions and also in major ecological changes that occur as new species associations form and species richness potentially decreases. Meta-analyses indicate that temperature rises in the twentieth century have led to shifts in species' range toward the poles that average 6.1 km per decade (Williams *et al*. 2007). Species with high dispersal capabilities may migrate at the rate of one kilometre per year or more, so that these species, together with climatically tolerant species, are likely to dominate many of the Earth’s ecosystems. Scientists also argue that species are less able to adapt to **(p.108)** climate warming today than at any other period in the last 10,000 years, due to the faster pace of change and to human-induced ecosystem changes, especially habitat change, which limit the possibilities for species to migrate and to adapt (Thomas *et al*. 2004). Both biodiversity losses and changes in species range can have multiple repercussions on ecosystems, in part due to changing species composition and richness.

Biodiversity-related tipping points

The tipping points (or critical threshold) concept has only quite recently been directly linked to the term ‘biodiversity’. The concept of biodiversity tipping points is generally closely allied to an ecosystems perspective, where it is thought that there are a number of key variables and dynamics that have a determining role in the organization of an ecosystem. Within any given system, there are alternative stable states (or ‘stability regimes’). For example, shallow lakes may be at one equilibrium with clear water and aquatic plants in place, or at another equilibrium where turbid water and a lack of vegetation persist (Scheffer *et al*. 2001). Beyond some limit, if there are even minor changes in the system, it can move over a threshold (or ‘tipping point’) into an alternative stable state that may be desirable or undesirable from the standpoint of the goods and services that it provides.

Not all ecosystem tipping points are closely related to biodiversity. But it appears that a large majority are, even though it is not always species diversity that plays a key role – it may be species abundance or only a few functionally important species. Scheffer’s (2009) work on critical transitions addresses lakes, oceans, and terrestrial ecosystems as case studies. Table 4.3 presents examples from terrestrial ecosystems where biodiversity change is central to the dynamics. In such cases, there are three types of relations that can be discerned where biodiversity change is related to tipping points in ecosystems:

1. Biodiversity change is driven by exogenous driver(s) (e.g. climate change).
2. There are feedbacks between biodiversity change and an exogenous driver (e.g. climate change–vegetation feedbacks).
3. Biodiversity change is the direct driver of change leading to tipping points.

An example of the first dynamic is change in species’ phenology due to warming or changes in precipitation that lead to changes in species’ range **(p.109)** or outbreaks of pests and diseases and thus reorganization of ecosystems. Examples of the second dynamic are the climate–vegetation feedbacks indicated in Table 4.3. Examples of the third are deforestation leading to changes in albedo, overhunting of large predators leading to the collapse of a trophic level, or certain ‘self-organizing’ effects of particular species. While each of these dynamics can lead to tipping points, in many cases all three may be occurring simultaneously and acting in synergy or antagonistically at different scales, but generally synergies between them lead to the highest probability of reaching tipping points.

A recent assessment of the vulnerability of Australian ecosystems to tipping points (Laurance *et al*. 2011) classified them into three sets according to the ‘severity’ of the tipping point: ‘tipping’ ecosystems, which are ‘likely to experience profound regime changes across most or all of their geographic range’; ‘dipping’ ecosystems, which experience such profound change but in geographically limited areas; and ‘stripping’ ecosystems which are ‘being stripped of important ecosystem components, such as their small mammal, amphibian, or large predator fauna, but such changes are more insidious and less visually apparent than major regime changes’.

Laurance *et al*. identified a number of intrinsic features of what they considered to be the ten most vulnerable ecosystems, as well as the major environmental threats. Of the seven intrinsic features identified, four relate directly to the species composition of these ecosystems: the history of habitat fragmentation; reliance on ecosystem engineers; reliance on framework species; and reliance on predators or keystone mutualists. Of the environmental threats, five (or six, depending on the causes of salinization) are related to climate change, one to pollution, and the rest to biodiversity change (habitat reduction, habitat fragmentation, changed fire regimes, invasives, overexploitation, and pests and pathogens). They found that most vulnerable ecosystems are threatened by multiple drivers, where synergies between drivers are pervasive and directly contribute to the likelihood of tipping points.

Recently, potential biodiversity-related tipping points have been identified that are seen to have larger-scale regional effects, where such effects are of great concern not only because of the implications these have for large numbers of smaller-scale ecosystems and the people who inhabit them, but also for global biodiversity per se, and for their potential contributions to other Earth systems tipping points. Leadley *et al*. (2010: 8) concluded that major biodiversity transformations will occur at levels near or below a low level of only 2°C global warming, including 'widespread **(p.110)**

Table 4.3 Examples of 'biodiversity' tipping points in terrestrial ecosystems (derived from Scheffer 2009: 216–39)

Dynamic	Ecosystem examples	Alternative states
Climate–vegetation feedbacks through albedo effects	Drylands – Sahel-Sahara – decrease in temperature contrast between ocean and land, weakening monsoon circulation	From wet vegetation state to desert state – drier conditions and loss of vegetation drove transition
Climate–vegetation feedbacks through transpiration	Amazon – deforestation decreases local moisture recycling	From wet forested state to dry savannah, and semi-desert, with expansion of tropical forest northward
Small-scale transitions in semi-arid vegetation	Herbivore mortality events trigger forest expansion	African savannah – Rinderpest epidemic reduced ungulate numbers allowing large-scale woodland expansion, then human-induced fire eliminated woodlands, and the open landscape again maintained by large herbivores
	Rare extreme weather events may trigger woodland expansion	Newly established vegetation may maintain itself through diverse mechanisms
	Self-organized vegetation patterns – transport of nutrients and water from barren land to vegetation patches	Loss of vegetation patches leads to desertic conditions devoid of perennial vegetation
	Alpine tree lines and lowland tree islands – sharp natural boundaries maintained through microclimates and soils	

Dynamic	Ecosystem examples	Alternative states
Forest–climate feedback in boreal regions	Boreal forest deforestation increases albedo effect, leading to cooling; global warming may promote forest expansion	Regional amplifier of global warming; terrestrial vegetation can affect ocean circulation patterns
	Lichen woodlands – closed lichen mat prevents tree recruitment	Quebec – shift from forest to lichen woodlands provoked by spruce budworm and fire
	Insect outbreaks – warm dry weather gives boost to spruce budworms	Cycles between spruce/fir-dominated to aspen/birch dominance, with moose browsing leading to shift back to spruce
Formation of raised bogs	Form in wet climates when shallow open waters are filled with organic matter – peat mosses achieve dominance	Semi-terrestrial states become bogs; atmospheric nitrogen input and drainage lead to vascular plant-dominated system
Species extinction in fragmented landscapes	Allee effect – e.g. positive feedback between meta-population size and local population size	Meta-population goes extinct through excessive fragmentation, may have cascading effects, e.g. loss of fish leading to switch in turbidity to clear state in ponds and lakes
Epidemics	Epidemics occur only beyond critical thresholds of population density and eventually vanish, but system tips	Transformation of boreal forest to lichen plains from spruce budworm; collapse of Caribbean coral reefs from disease in sea urchins

(p.111) **(p.112)** coral reef degradation, large shifts in marine plankton community structure especially in the Arctic ocean, extensive invasion of tundra by boreal forest, destruction of many coastal ecosystems, etc.' They found that 'the risk of catastrophic biodiversity loss … has been substantially underestimated in previous global biodiversity assessments … Most of the biodiversity tipping points that we have identified will be accompanied by large negative regional or global scale impacts on ecosystem services and human well-being.' The main regional tipping points they identified are presented in the box below. **(p.113)** **(p.114)**

Possible regional tipping points with global repercussions (from Leadley *et al.* 2010)

The Amazon Forest 'due to the interaction of deforestation, fire and climate change, undergoes a widespread dieback, changing from rainforest to savanna or seasonal forest over wide areas, especially in the East and South of the biome. The forest could move into a self-perpetuating cycle in which fires become more frequent, drought more intense and dieback accelerates. Dieback of the Amazon will have global impacts through increased carbon emissions, accelerating climate change. It will also lead to regional rainfall reductions that could compromise the sustainability of regional agriculture' (p. 24). See also Toby Gardiner (4.3).

The African Sahel: ‘under pressure from climate change and over-use of limited land resources, [the Sahel] shifts to alternative, degraded states, further driving desertification. Severe impacts on biodiversity and agricultural productivity result. Continued degradation of the Sahel has caused and could continue to cause loss of biodiversity and shortages of food, fibre and water in Western Africa’ (p. 24). See Emily Boyd (7.2).

Island Ecosystems ‘are afflicted by a cascading set of extinctions and ecosystem instabilities, due to the impact of invasive alien species … As the invaded communities become increasingly altered and impoverished, vulnerability to new invasions may increase … Because islands are the global hotspot for endemic species local eliminations often constitute global extinctions … [There are also] large negative impacts of many invasive species on ecosystem services such as plant productivity, nutrient cycling, water supply, etc.’ (p. 23).

The Tundra: ‘boreal forests will permanently replace tundra ecosystems if current trends of greenhouse gas emissions persist … These changes in tundra systems substantially increase climate warming in many models. Permafrost melting and changes in game availability have already heavily impacted some indigenous populations and these impacts are likely to become widespread and severe over the coming decades … The invasion of tundra by boreal forests can have a profound impact on global temperatures since low surface albedo from boreal forests during the winter season warms climate compared to tundra’ (p. 53).

Coastal Terrestrial Systems and Sea-level rise of 20–60 cm or more by 2100 are likely and will continue for many centuries, with greatest impacts on coastal wetlands where sediment elevations are reduced, and where species migration landward is prohibited due to physiographic setting or urban development. Biodiversity impacts are large due to habitat loss and ecosystem area loss and degradation will increase ‘coastal hazards to human settlements, reduce coastal water quality, release large quantities of stored carbon, etc.’ (p. 25).

Marine Fisheries: The tipping point consists of changes in the composition of marine communities, where large predator populations collapse and communities are dominated by organisms lower in the food chain where, in addition to overfishing, ocean warming and acidification are additional threats to marine biodiversity. ‘Allowing global ocean fisheries to reach a tipping-point will not only affect marine biodiversity but it will also undermine life on the planet because of the immense importance of the global ocean to biogeochemical cycles … Total fish catch in the global ocean may be reduced to up to a tenth of its peak amount by 2048. This will result in significant negative economic and social effects, especially on some of the world’s most vulnerable human communities’ (p. 117).

Tropical Coral Reefs: These global biodiversity hotspots ‘provide a broad range of ecosystems services with high socio-economic value: tourism, fisheries (food and employment), nutrient cycling, climate regulation, protection of the shoreline and other ecosystems (e.g. mangroves), and constitute the habitat for a wide range of species’, but rising CO_2 concentrations will lead to levels of acidification that severely impede calcium carbonate accretion, while global warming leads to coral bleaching. ‘If current trends continue coral reef ecosystems may undergo regime shifts from coral to sponge or algae dominated habitats. The tipping point for this phase shift is estimated to be a sea-surface temperature increase of 2°C and/or atmospheric CO_2 concentrations above 480 ppm (estimated to occur by 2050)' (p. 125).

Not all scientists agree with the projections about potential tipping points. For example, Willis *et al*. (2010) argue that fossil records covering intervals of time when magnitudes and rates of climate change were similar to those projected for the twenty-first century show that these were not associated with large-scale biodiversity extinctions. They note that one of the most biodiverse periods in the neotropics occurred during the Eocene Climatic Optimum (53–51 million years ago), when atmospheric CO_2 exceeded 1200 ppmv and tropical temperatures were 5–10 degrees warmer than now. The tropical forest biome extended to mid-latitudes in the northern and southern hemisphere and there was no ice at the poles. They note that models presume less ecological tolerance of species than is likely and that finer-grained resolution models predict far lower extinction rates than grosser resolution models. However, a World Bank report (Vergara and Scholtz 2011) also models CO_2 effects and concludes that the synergies between climate change, deforestation, and forest fires could well lead to major impacts as soon as 2025.

Regional level biodiversity tipping points and human resilience

There is a pressing need to begin to assess the vulnerabilities of different groups of people to the pain and suffering, and loss of livelihoods (and **(p.115)** indeed of life) associated with potential and real biodiversity-related tipping points. As a case in point, some scientists predict that much of the Amazon basin region could surpass a tipping point described in the box above, with some of it 'flipping' to savannah. A World Bank-sponsored modelling exercise that assessed this threat found that, with the interacting effects of climate change, deforestation, and fire, 'Substantial impacts are already projected by 2025 and the situation worsens by 2050. The effect of climate change alone would contribute to reduce the extent of the rainforest biome by one third by the end of the century' (Vergara and Scholtz 2011). Vergara presented a qualitative assessment of the likely implications:

> Direct economic losses … include yields and areas for specific crops in tropical areas … as temperatures increase and rainfall patterns are modified, and the ideal areas for different crops shift … dieback may reduce rainfall in agricultural areas in southern Brazil … Sustainable forestry would also be affected … [and the] magnitude of the carbon sink would likewise be diminished. In addition, weather extremes, longer dry periods, disappearance or reduction of dry-period rainfalls and increased intensity during rainy periods would all affect stream-flow regulation. This would have an impact on the firm capacity of existing hydropower plants and on the water storage capacity of future investments.
>
> (Vergara 2010: 74–75)

The 2011 report called for ‘a full account of losses … a better valuation of the financial and natural capital represented by the Amazon ecosystem is required as well as a more comprehensive assessment of the economic implications of its potential dieback’ (Vergara and Scholtz 2011: 63). The concern, however, is not for the impacts on human beings, but for ‘economic losses’, ‘financial and natural capital’, ‘yields’, and so forth. What, then, might be anticipated for human well-being in the region? Toby Gardiner (4.3) looks at this, but here are some possible outcomes that might be derived from the World Bank study:

- The livelihoods base of many indigenous forest peoples (perhaps a majority of the 349 ethnic groups) might collapse, which might lead to their virtual disappearance.
- There would be loss of much non-indigenous agriculture, fisheries, and forest industries and thus loss or collapse of self-sufficient production as well as rural employment in the areas worst affected.
- Rural populations would be regionally displaced in order to continue to fish, farm, and harvest forests.
- Rural–urban migration would occur on a mass scale. **(p.116)**
- There would be chronic water, food, and energy shortages in urban areas, affecting nearly all populations but particularly the majority, who are poor.
- High unemployment in urban areas would result from direct and indirect loss of economic activities, including tourism.
- National and regional level economic crises would result from loss of export revenues, rising social insecurity, and attempts to substitute for lost ecosystem services.
- There would be increasing conflict, violence, and social instability at sub-national, national, and even inter-basin levels.
- Unemployment and displacement would result in high levels of migration to other nations and continents.

The implications for human welfare beyond the region might not be limited to the ramifications for downstream and upstream markets and employment (e.g. timber, soya, meat, minerals, etc.) and the regional and global financial system, or to the effects of international migration flows or national and regional conflicts. As the Amazon tips from a net greenhouse gas absorber to a net source of greenhouse gases, it will be extremely difficult to avoid exceeding ‘dangerous’ levels of global warming even if CO_2 reductions in other areas are achieved (Cox *et al*. 2003), with all of the implications that this has for humanity’s efforts at climate change mitigation and adaptation.

Whether or not such scenarios closely or remotely reflect our possible futures, there are very strong reasons to develop them carefully and systematically based upon our best current knowledge, and for policymakers and for the public to pay close attention. Had scientists neglected to make clear the potential consequences of nuclear war for humanity and the types of devastation that were implied, it is possible that such a war would not have been averted until now. Knowing the implications for human suffering and for the future of the human species (e.g. from a possible nuclear winter) has been of inestimable importance in mobilizing public and political support on all sides of the political spectrum to limit nuclear weapons and avoid even limited nuclear warfare.

At the same time, there are very important measures that we must begin to take with equal seriousness at local scales. Adaptation to local-scale tipping points can have very major repercussions not only for regional and global level environmental change and equity, but also for human resilience in the face of local, regional, and global tipping points of all sorts.

(p.117) Bio-cultural diversity and resilience

Humans have substantially altered some 77 per cent of the Earth's ice-free land, half of which is in agricultural or urban use (Ellis and Ramankutty 2008). Throughout much of human existence, humans have altered ecosystems and the biodiversity that these contain in the effort to ensure livelihoods and cultural integrity across generations. In the process, humans have often intentionally increased the biodiversity that is useful to them for food, fibre, fodder, fuel, medicinal uses, cash, and other cultural purposes, and this has modified landscapes in ways that support a multitude of other life forms. Most of the world's terrestrial biodiversity exists outside of protected areas in biologically and ecologically complex human-dominated landscapes.

Biodiversity constitutes the principal form of wealth for a large part of humanity. This includes about 2.8 billion people who live in rural areas of the least developed countries, 2.4 billion of whom subsist from agriculture. They constitute nearly 35 per cent of the world's population (FAO 2004), and feed a considerably larger proportion of the world's population. About half of the world's farmers rely on no- or low-input agroforestry farming systems ('traditional agriculture') (World Bank 2002), which generally tend to be biodiversity-rich polycultures (Vandermeer 2002). Nearly 250 million people live in forests and depend on them to a high degree, while some 60 million indigenous people are almost wholly dependent on forest biodiversity for their livelihoods (World Bank 2002). Another 50 million people in developing countries depend on small-scale fisheries (ICLARM 2001).

It is estimated that about a billion people regularly consume wild foods (Sunderland 2011: 266, citing Pimentel *et al*. 1997). While there is no global inventory of all plant species that have direct-use values for humans, PROSEA (Plant Resources of South-East Asia)[2] recorded nearly 6000 species that are used in that region, which Heywood (1999) extrapolated to some 18,000–25,000 species for the tropics as a whole – excluding the 25,000 species that are herbal medicines.[3] The FAO Global Databank on Animal **(p.118)** Genetic Resources (covering 182 countries) contains a total of 14,017 livestock breeds (FAO 2007), and it is estimated that humans consume around 1200 insect species (DeFoliart 2012). It is not only tropical biodiversity that directly supports humans – even in the Arctic, people consume in excess of a hundred local species, which represent the traditional and nutritionally rich components of their diets (Kuhnlein and Receveur 1996). About 1.3 billion people live from 'environmentally fragile' lands (World Bank 2003), where environmental disturbances and disequilibria are the rule rather than the exception, and people must be adapted to living with environmental hazard, risk, and extremes. Biological resources constitute the foundations of these people's cultural and material heritage, and the substance of the knowledge and practices that they pass on to future generations (Balée and Erickson 2006; Salick and Byg 2007).

Some small-scale societies are heavily dependent on only a few species, and some of these are located in areas that are relatively poor in biological diversity, as is the case with Touareg camel pastoralists in the Sahara, Inuit caribou hunters in northern Canada, and date palm (*Phoenix dactylifera L.*) farmers in the Arabian Peninsula. Even small changes in local biodiversity can present major threats to these populations' food supply and to the availability of fuel, medicine, fibre, construction materials, and other plant-and animal-derived resources. Some live in areas that are very rich in biological diversity – such as the Nuaulu of Seram who depend on sago palm

(*Metroxylon sagu*), Amerindian swidden gardeners who exchange cassava (*Manihot esculenta*) in Amazonia, or Ethiopian Aari ensete (*E. ventricosum*) producers. Such species are considered to be ‘cultural keystones’, so important are they to livelihoods, social organization, and cultural identity (Christancho and Vining 2004; Garabaldi and Turner 2004). These species have ecological and cultural functions that are not readily substitutable, which renders the populations that depend on them more vulnerable to abrupt change. The loss of such species, or of the species that these same species depend upon (e.g. pasture grasses that camels consume), or an outbreak of a pest or disease that seriously affects the productivity of these species, could create many adverse effects not only for livelihoods, but also for social organization and demographics. Nevertheless, global biodiversity assessments focus on ecological keystone species while ignoring such cultural keystones. Accordingly, the vulnerability of populations that are dependent on a few species when facing biodiversity change is as yet largely unexplored, so their vulnerability is unrecorded.

(p.119) Yet highly biodiversity-dependent societies may offer better prospects for continued evolution given biodiversity tipping points in comparison with systems that are highly dependent on external inputs (e.g. fossil fuels, chemicals, irrigation) and markets, with high population densities and high demands on natural resources and ecosystem services close to ecosystem thresholds. Adapting intensive systems to biodiversity change generally implies even greater intensification. Pest outbreaks, for example, are fought with higher levels of pesticide use, weed invasions with more herbicides, and soil biodiversity loss leads to higher levels of fertilizer use, which are likely to further compound the negative consequences of biodiversity change, price increases, etc. (see e.g. Lal 2007; IFDC 2008; Pimentel and Pimentel 2008; Smil 2008). Tim Lang and John Ingram discussed the context in Chapter 4.1.

Dobson *et al*. (2006) provided a general framework for understanding the ecological consequences of species and population losses for a partial collapse of ecosystems that they relate to habitat loss, but that may also be seen as applicable in relation to other drivers of change. They note that decreases in biodiversity should lead to reductions in ecosystem functioning, but this depends in part on the order in which species are lost or gained. If only a few species provide a function or service, decline in the service may be rapid if these species decline or disappear. Other services may be provided by functionally redundant competing species, so decline in one species is compensated by the increase in another. When habitats degrade, species at higher trophic levels are usually lost more rapidly than those at lower levels, and species at different trophic levels perform different ecosystem functions, so ‘we might expect to see a predictable hierarchical loss of ecosystem services as habitats are eroded’ (p. 1917).

The loss of some species at a specific trophic level may occur slowly and be compensated by the remaining species, until a point is reached through further species loss when a drastic decrease in ecosystem services occurs. At the other extreme, if the trophic level consists of a few rare or fragile species, then small changes in species biodiversity may result in large and rapid changes in ecosystem services. Most ecosystems will fall somewhere between these two boundaries, where ‘a linear decrease in the service [follows] as each species is lost … in essence, the loss of each individual species results in the loss of a “unit” of ecosystem service’ (p. 1918). Dobson *et al*. provide a table (Table 1, p. 1919) that relates the susceptibility of different ecosystem functions to species loss for different ecosystems. Their model suggests that ‘the collapse of ecosystem services will be determined **(p.120)** by a hierarchical series of nested thresholds, or breakpoints, whose magnitude will occur at different levels of decline in overall species abundance' where the most resilient species are at the bottom, and the least at the top, of the food chain (acknowledging that there are exceptions). They conclude that:

> because different ecosystem services tend to be undertaken by species at different trophic levels and because trophic webs will tend first to thin and then collapse from top to bottom, we would expect to see a predictable hierarchical and sequential loss of the economic goods and services by natural ecosystems as they become eroded and degraded by anthropogenic activities.
>
> (Dobson *et al*. 2006: 1925)

They warn that current dis-attention to the goods and services provided by species at different trophic levels means that there is also limited incentive to conserve these species.

The first requirement of any analysis of biodiversity change must be to characterize and understand the types of dependencies, or inter-dependencies, that different human population groups have with: rare or fragile species; cultural, ecosystem or economic keystone species; specific trophic levels; specific functional groups; and specific ecosystem services. The second is to deal with the question of how people are likely to adapt or maladapt to such phenomena. Tipping points do not occur overnight. Many ecosystems, trophic levels, etc. are already crossing thresholds towards alternative states; others are manifesting 'early warnings' (e.g. slower recovery from perturbations, increasing variance, increasing autocorrelation, flickering, and increased spatial coherence) (Scheffer 2009; Scheffer *et al*. 2009). Early warnings related to biodiversity loss have already been identified (e.g. for invasive species, see EEA 2010; for biodiversity change in general, see the indicators used in the Swiss Biodiversity Monitoring System[4]), and there is now a very interesting attempt to identify early warning indicators of biodiversity change in relation to local livelihoods in small island developing states in relation to the vulnerability of the rural poor, the status of resources important to nutrition, for food and medicine, and for access and benefit sharing, among others (Teelucksingh and Perrings 2010).

It is no coincidence that the globe's sixth extinction of species is occurring together with an unprecedented extinction of human cultures, where both are driven by similar underlying phenomena, and thus the current biodiversity crisis should be reconceived as a crisis of 'bio-cultural **(p.121)** diversity' (e.g. Sutherland 2003; Maffi 2005; Rozzi 2012). Half of the globe's cultures/languages are likely to be lost by the end of this century; at least as high a proportion of many rural subsistence socio-ecological systems are likely to disappear, as is the case, for example, of the San Bushmen of the Kalahari (e.g. Hitchcock 2006), the Ifaguo of the Philippines (Guimbatan and Baguilat 2006), and the Hani in Southwest China (Xu *et al*. 2009). Campaigns for the preservation of endangered cultures are rare; in fact, such cultures are often portrayed as the cause of species' loss and the provokers of degradation of forests and other areas that are mistakenly considered by outsiders to be 'pristine' environments.[5]

Scientists and policymakers often think that our resilience as a species is based on science, technology, economic growth, accumulated wealth, and modern democratic institutions, whereas in fact it is more likely to be based on the more than 6700 cultures/languages[6] across the globe that have evolved vast knowledge, technologies, and a myriad of institutions that have managed largely to meet the human needs that these have culturally defined, most often without compromising, and usually by enhancing, their natural base of existence, at times over millennia. Prioritizing and supporting such rural subsistence societies could be seen as a global insurance policy, so that the cultures, biodiversity, agro-biodiversity and ecosystem services that are crucial to the world's future continue to exist. The study of such systems and the ways in which traditional peoples maintain and use biodiversity can speed the emergence of the agro-ecological principles which are urgently needed to develop more sustainable agro-ecosystems and agro-biodiversity conservation strategies both in industrial and developing countries (Denevan 1995).

If we are indeed to be able to negotiate tipping points and meet the unprecedented challenges that we face as a species, we must transform our **(p.122)** ways of thinking about our own species, going beyond a simple awareness that places and things of great beauty, harmony, and intrinsic and monetary value are disappearing for ever. It will be necessary to realize that the human race must maintain its cultural and technological options in case our great experiment of 'development' fails.

At this moment, then, we are beginning seriously to wonder whether the 'end-point' of 'development' toward which we have been racing might indeed be the wrong one. Many are coming to realize that, in spite of our vast accumulated wealth of scientific knowledge, we still seem to know very little about how to live in and with the natural world. In fact, we are just beginning to realize that we must attempt to retain the tremendous adaptive capacity, knowledge, and cultural resilience that have allowed people to occupy and thrive in virtually every ecosystem on earth over a long period of time. It is no coincidence that, with biodiversity loss, we are losing the basis of our physical existence, at the same time that we are also losing the basis of our collective resilience with the mass loss of human cultures.

Current adaptation thinking is based on the assumption that adaptation can be rationally planned, funded, and managed or engineered, which downplays the significance of autonomous adaptation at local levels, which anthropological research shows is manifest in mobility, exchange, rationing, resource pooling, diversification, intensification, innovation, and revitalization (Thornton and Manasfi 2010). Such studies suggest that the most resilient and adaptive social unit over long periods may be the household rather than the community or state, and that adaptation must be viewed not as a singular strategy, but as a set of diverse, intersecting decision-making and behaviour-changing processes that may evolve autonomously or through planning in response to a multitude of interacting biotic and non-biotic stressors. Understanding adaptation necessitates understanding of the dynamic flows and feedbacks between natural processes and human intentions and actions. Indeed, the hope is that humans can manage to adapt their social-ecological systems in ways that mitigate biodiversity change, support ecosystem resilience, and ensure human well-being. Human maladaptation will surely spell human and ecological disaster. Supporting human adaptation research and policy-making can only be conducive to adaptation.

(p.123) References

Bibliography references:

Balée, W. and Erickson, C. (2006), 'Time, Complexity and Historical Ecology', in W. Balée and C. Erickson (eds), *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands* (New York: Columbia University Press), 1–17.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.B., *et al*. (2011), 'Has the Earth's Sixth Mass Extinction Already Arrived?', *Nature*, 471: 51–57.

Chivian, E. and Bernstein, A. (eds) (2008), *Sustaining Life: How Human Health Depends on Biodiversity* (Oxford: Oxford University Press).

Christancho, S. and Vining, J. (2004), 'Culturally Defined Keystone Species', *Human Ecology Review*, 11 (2): 153–64.

Convention on Biological Diversity (CBD), Secretariat (2010), *Global Biodiversity Outlook 3* (Montreal: CBC). Available online at: www.cbd.int/GBO3 (accessed 6 June 2012).

Cox, P.M., Betts, R.A., Collins, M., Harris, P., Huntingford, C., and Jones, C.D. (2003), *Amazon Dieback under Climate-Carbon Cycle Projections for the 21st Century, Hadley Centre Technical Notes 42* (Exeter: Hadley Centre, Met Office).

DeFoliart, G. (2012), *The Human Use of Insects as a Food Resource: A Bibliographic Account in Progress* (Madison, WI: University of Wisconsin-Madison, Dept. of Entomology), e-book available through: http://www.food-insects.com/ (accessed 5 June 2012).

Denevan, W. (1995), 'Prehistoric Agricultural Methods as Models for Sustainability', *Advances in Plant Pathology*, 11: 21–43.

Dobson, A., Lodge, D., Alder, J., Cumming, G.S., Keymer, J., McGlade, J., *et al*. (2006), 'Habitat Loss, Trophic Collapse, and the Decline of Ecosystem Services', *Ecology*, 87 (8): 1915–24.

Ellis, E.C. and Ramankutty, N. (2008), 'Putting People in the Map: Anthropogenic Biomes of the World', *Frontiers in Ecology and the Environment*, 6 (8): 439–47.

FAO (2007), *The State of the World's Animal Genetic Resources for Food and Agriculture* (Rome: FAO).

Food and Agriculture Organization of the United Nations (2004), *The State of Food and Agriculture 2003–2004* (Rome: FAO).

Garabaldi, A. and Turner, N. (2004), 'Cultural Keystone Species: Implications for Ecological Conservation and Restoration', *Ecology and Society*, 9 (3): article 1.

Guimbatan, R. and Baguilat, T. (2006), 'Misunderstanding the Notion of Conservation in the Philippine Rice Terraces: Cultural Landscapes', *International Social Science Journal* (UNESCO), March: 59–67.

Heywood, V. (1999), 'Trends in Agricultural Biodiversity', in J. Janick (ed.), *Perspectives on New Crops and New Uses* (Alexandria, VA: ASHS Press), 2–14.

Hitchcock, R.K. (2006), '"We Are the Owners of the Land": The Struggle of the San for the Kalahari and Its Resources', in R.K. Hitchcock, K. Ikeya, M. Biesele and R.B. Lee (eds), *Updating the San: Image and Reality of an African People in the 21st Century, Senri Ethnological Studies 70* (Osaka: National Museum of Ethnology), 229–56. **(p.124)**

International Center for Living Aquatic Resources Management (ICLARM) (2001), *ICLARM Medium Term Plan 2002–2004* (Manila: ICLARM).

International Fertilizer Development Center (IFDC) (2008), 'World Fertilizer Prices Soar as Food and Fuel Economies Merge', *IFDC Report*, 33 (1): 1–3.

Jax, K. (2010), *Ecosystem Functioning* (Cambridge: Cambridge University Press).

Keesing, F., Belden, L.K., Daszak, P., Dobson, A., Harvell, C.D., Holt, R.D., *et al*. (2010), 'Impacts of Biodiversity on the Emergence and Transmission of Infectious Diseases', *Nature*, 468: 647–52.

Kuhnlein, H. and Receveur, O. (1996), 'Dietary Change and Traditional Food Systems of Indigenous Peoples', *Annual Review of Nutrition*, 16: 417–42.

Lal, R. (2007), 'Anthropogenic Influences on World Soils and Implications for Global Food Security', *Advances in Agronomy*, 93: 69–93.

Laurance, W.F., Dell, B., Turton, S.M., Lawes, M.J., Hutley, L.B., McCallum, H., *et al*. (2011), 'The 10 Australian Ecosystems Most Vulnerable to Tipping Points', *Biological Conservation*, 144 (5): 1472–80.

Leadley P., Pereira, H.M., Alkemade, R., Fernandez-Manjarrés, J.F., Proença, V., Scharlemann, J.P.W., and Walpole, M.J. (2010), *Biodiversity Scenarios: Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services, Technical Series no. 50* (Montreal: Secretariat of the Convention on Biological Diversity).

Maffi, L. (2005), 'Linguistic, Cultural, and Biological Diversity', *Annual Review of Anthropology*, 34: 599–617.

Malcolm, J.R., Markham, A., Neilson, R.P., and Garaci, M. (2005), 'Migration of Vegetation Types in a Greenhouse World', in T. Lovejoy and L. Hannah (eds), *Climate Change and Biodiversity* (New Haven, CT, Yale University Press), 252–55.

Pereira, H.M., Leadley, P.W., Proença, V., Alkemade, R., Scharlemann, J.P.W., Fernandez-Manjarrés, J.F., *et al*. (2010), 'Scenarios for Global Biodiversity in the 21st Century', *Science*, 330: 1496–1502.

Pimentel, D. and Pimentel, M.H. (2008), *Food, Energy, and Society* (Boca Raton, FL: CRC Press).

Pimentel, D., McNair, M., Buck, L., Pimentel, M., and Kamil, J. (1997), 'The Value of Forests to World Food Security', *Human Ecology*, 25: 91–120.

Pongsiri, M.J., Roman, J., Ezenwa, V.O., Goldberg, T.L., Koren, H.S., Newbold, S.C., *et al*. (2009), 'Biodiversity Loss Affects Global Disease Ecology', *BioScience*, 59 (11): 945–54.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., and Kunin, W.E. (2010), 'Global Pollinator Declines: Trends, Impacts and Drivers', *Trends in Ecology and Evolution*, 25 (6): 345–53.

Root, T.L. and Hughes, L. (2005), 'Changes in Phenology and Ecological Interactions', in T.E. Lovejoy and L. Hannah (eds), *Climate Change and Biodiversity* (New Haven, CT: Yale University Press), 61–69.

Rozzi, R. (2012), 'Biocultural Ethics: Recovering the Vital Links Between the Inhabitants, Their Habits, and Habitats', *Environmental Ethics*, 34 (1): 27–50.

Salick, J. and Byg, A. (eds) (2007), *Indigenous People and Climate Change, Report of Symposium 12–13 April 2007, Environmental Change Institute, Oxford* (Oxford: **(p.125)** Tyndall Centre for Climate Change Research). Available online at: http://www.ecdgroup.com/docs/lib_004630823.pdf (accessed 6 June 2012).

Scheffer, M. (2009), *Critical Transitions in Nature and Society* (Princeton, NJ: Princeton University Press).

Scheffer, M., Westley, F., Brock, W., and Holmgren, M. (2001), 'Dynamic Interaction of Societies and Ecosystems: Linking Theories from Ecology, Economy and Sociology', in L.H. Gunderson and C.S. Holling (eds), *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington DC: Island Press), 195–240.

Scheffer, M., Bascompte, J., Brock, W.A., Brovkin, V., Carpenter, S.R., Dakos, V., *et al*. (2009), 'Early-Warning Signals for Critical Transitions', *Nature*, 461: 53–59.

Smil, V. (2008), *Energy in Nature and Society* (Cambridge, MA: MIT Press).

Steinfeld, H., Mooney, H.A., Schneider, F., and Neville, L.E. (2010), *Livestock in a Changing Landscape, Vol. 1* (Washington DC: Island Press).

Sunderland, T.C.H. (2011), 'Food Security: Why Is Biodiversity Important?, *International Forestry Review*, 13 (3): 265–74.

Sutherland, W. (2003), 'Parallel Extinction Risk and Global Distribution of Languages and Species', *Nature*, 423: 276–79.

Teelucksingh, S.S. and Perrings, C. (2010), *Biodiversity Indicators, Ecosystem Services and Local Livelihoods in Small Island Developing States (SIDS): Early Warnings of Biodiversity Change* (Nairobi: UNEP).

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., *et al*. (2004), 'Extinction Risk from Climate Change', *Nature*, 427: 145–48.

Thornton, T.F. and Manasfi, N. (2010), 'Adaptation – Genuine and Spurious: Demystifying Adaptation Processes in Relation to Climate Change', *Environment and Society: Advances in Research*, 1: 132–55.

Tilman, D. and Lehman, C. (2001), 'Human-Caused Environmental Change: Impacts on Plant Diversity and Evolution', *Proceedings of the National Academy of Sciences USA*, 98 (10): 5433–40.

Vandermeer, J.H. (ed.) (2002), *Tropical Agroecosystems* (Boca Raton, FL: CRC Press).

Vergara, W. (ed.) (2010), *Assessment of the Risk of Amazon Dieback: Main Report, Environmentally and Socially Sustainable Development Department Latin America and Caribbean Region* (Washington DC: World Bank).

Vergara, W. and Scholz, S.M. (eds) (2011), *Assessment of the Risk of Amazon Dieback, World Bank Study* (Washington DC: World Bank).

Western, D. (2001), 'Human-Modified Ecosystems and Future Evolution', *Proceedings of the National Academy of Sciences USA*, 98 (10): 5458–65.

Williams, J.W., Jackson, S.T., and Kutzbach, J.E. (2007), 'Projected Distributions of Novel and Disappearing Climates by 2100 AD', *Proceedings of the National Academy of Sciences USA*, 104 (14): 5738–42.

Willis, K., Bennett, K.D., Bhagwat, S.A, and Birks, H.J.B. (2010), '4°C and Beyond: What Did This Mean for Biodiversity in the Past?', *Systematics and Biodiversity*, 8 (1): 3–9. **(p.126)**

Wise, M., Calvin, K., Thomson, A., Clarke, L., Bon-Lamberty, B., Sands, R., *et al*. (2009), 'Implications of Limiting CO_2 Concentrations for Land Use and Energy', *Science*, 324: 1183–86.

Woodruff, D. (2001), 'Declines of Biomes and Biotas and the Future of Evolution', *Proceedings of the National Academy of Sciences USA*, 98 (10): 5471–76.

World Bank (2002), *A Revised Forest Strategy for the World Bank Group* (Washington DC: World Bank).

World Bank (2003), *World Development Report 2003 – Sustainable Development in a Dynamic World: Transforming Institutions, Growth, and Quality of Life* (Washington DC: World Bank).

Xu, J.C., Lebel, L., and Sturgeon, J. (2009), 'Functional Links Between Biodiversity, Livelihoods and Culture in a Hani Swidden Landscape in Southwest China', *Ecology and Society*, 14 (2): article 20.

Notes:

([1]) This work is based on the 'Human Adaptation to Biodiversity Change' Project NE/ 1004122/1, which was partly funded with support from the Ecosystem Services for Poverty Alleviation (ESPA) programme. The ESPA programme is funded by the Department for International Development (DfID), the Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC).

([2]) See http://www.prosea.nl/.

([3]) Heywood (1999) noted that the Andres Bello Convention (involving Bolivia, Colombia, Chile, Ecuador, Spain, Panama, Peru, and Venezuela) has identified over a thousand native species that have 'not been extensively domesticated, are underutilised, or little known but with economic potential'. 'Another major source of agro-biodiversity is the tens of thousands of species that are grown in a pre- or semi-domesticated state on home gardens or similar polycultures … many thousands more are harvested wild to supplement farm household incomes … [but] our knowledge of their most basic biology and agronomy is virtually non-existent and we must depend on knowledge developed over long periods by local farming societies.'

([4]) http://www.biodiversitymonitoring.ch/english/aktuell/portal.php.

([5]) In the West, even the term 'culture' is widely misunderstood (e.g. known in reference to the arts) or regarded with suspicion: it is not generally considered to be the subject of serious policy attention or scientific inquiry, and is conveniently bundled off into underfunded disciplines such as anthropology and sociology.

([6]) The 6700 languages across the globe are not identical with cultures. However, language is considered as an acceptable proxy for cultures, where UNESCO notes: ‘Languages are humankind’s principal tools for interacting and for expressing ideas, emotions, knowledge, memories and values. Languages are also primary vehicles of cultural expressions and intangible cultural heritage, essential to the identity of individuals and groups. Safeguarding endangered languages is thus a crucial task in maintaining cultural diversity worldwide’ (http://www.unesco.org/culture/ich/index.php?lg=ENandpg=00136).