Human Adaptation to Biodiversity Change: Facing the Challenges of Global Governance without Science?

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Abstract

This paper argues that biodiversity change threatens the livelihoods, food security, and cultural and ecological integrity of many rural peoples across the developing world. Massive loss of crop varieties and of wild flora and fauna that people develop and use to meet most of their biological and cultural needs is by now certain for many regions including, but certainly not limited to, biodiversity hotspots. Changes in species' phenology and range will also lead to new species configurations and related changes in ecosystem services (affecting e.g. soil fertility, pest and disease incidence, etc.) and people will have to adapt to these changes. Some local responses to such change may mitigate loss of biodiversity and related ecosystem services, and others may exacerbate these trends. Responses can be positive or negative for human well being at different scales. In spite of major international initiatives toward conserving biodiversity and toward understanding and facilitating adaptation to climate change, there is currently very little research, and no research programme, directed at understanding adaptation to biodiversity change; international mechanisms such as the Convention on Biological Diversity's AHTEG on Biodiversity and Climate Change are ill-equipped to integrate science and governance. Change drivers are not limited to climate change, and it is biodiversity change that will largely determine vulnerability and resilience to climate change. Scientists and policy makers thus lack conceptual frameworks, tools and mandates to support adaptation governance while mitigating biodiversity change. Such research must address questions such as: How quickly can human populations respond to changes in species composition and richness, and 're-engineer' social-ecological systems in ways that are desirable in terms of human welfare and ecosystem services? What are the intended and unintended effects, or emergent properties, of human responses to biodiversity and related ecosystem change? What impairs, and what facilitates, adaptive human responses, and what influences the outcome in terms of human welfare, biological diversity and ecosystem functioning? Are there 'black box' variables that facilitate or impede adaptation at local scales and can they be illuminated by science? How are cultural values, economic systems, institutional arrangements, knowledge, social and physical mobility, linked or not to human capacity to respond or adapt to rapid biological and ecological change? Are there predictable trajectories of response given particular patterns of change, environments and social-economic systems, and are there variables and processes that cut across such systems? Are such changes so rapid and significant that they overwhelm human capacity to respond or are humans, especially those in highly biodiversity dependent societies, highly capable innovators that can provide lessons for humanity at large? An outline of an agenda for international research and policy interface in this field is proposed.

1. The Nature and Implications of Scientific Ignorance for Global Governance

The United Nations declared 2010 as the "International Year of Biodiversity" to raise global awareness about the unprecedented loss of our planet's life in the massive extinction of species. The Nagoya Biodiversity Summit to be held in October, 2010, will adopt a new strategic plan for implementing the UN Convention on Biological Diversity, whose current targets for reducing the rate of biodiversity loss[1] by 2010 will not be met. This new plan will call for strategic actions to mitigate biodiversity loss and promote adaptation to the accelerated loss of biodiversity that will occur over the 21st century and beyond. The plan will also call for greater integration between climate change and biodiversity mitigation and adaptation science and policy efforts. What is likely to be missing, however, is substantive attention to the question of how humans are adapting, or may in future adapt, to biodiversity change, or of the implications of such adaptation for biodiversity or climate change mitigation, or for human welfare.

In a nutshell, the reason that this topic will not be on the agenda is that it is not currently considered systematically in any of the globe's major policy forums, such as the Convention on Biological Diversity's Ad Hoc Technical Expert Group on Biodiversity and Climate Change, or in national or regional forums. This is hardly surprising given that, although there is a substantial and rapidly growing body of scientific knowledge on biodiversity change and *species* adaptation, there is currently no scientific research programme dealing with *human* adaptation to biodiversity change. Scientists argue that, no matter what humans do to alter global environmental change processes in the upcoming decades, species will have to adapt individually to the massive changes that are already occurring and that are irreversible. Ironically, the only species that appears to be omitted from consideration is the human species. In this paper I discuss the nature and significance of this omission, explore the state-of-the-art of knowledge about autochthonous human adaptation to biodiversity change, and propose ways to move forward with a scientific-policy agenda.

1.1 The significance of biodiversity change

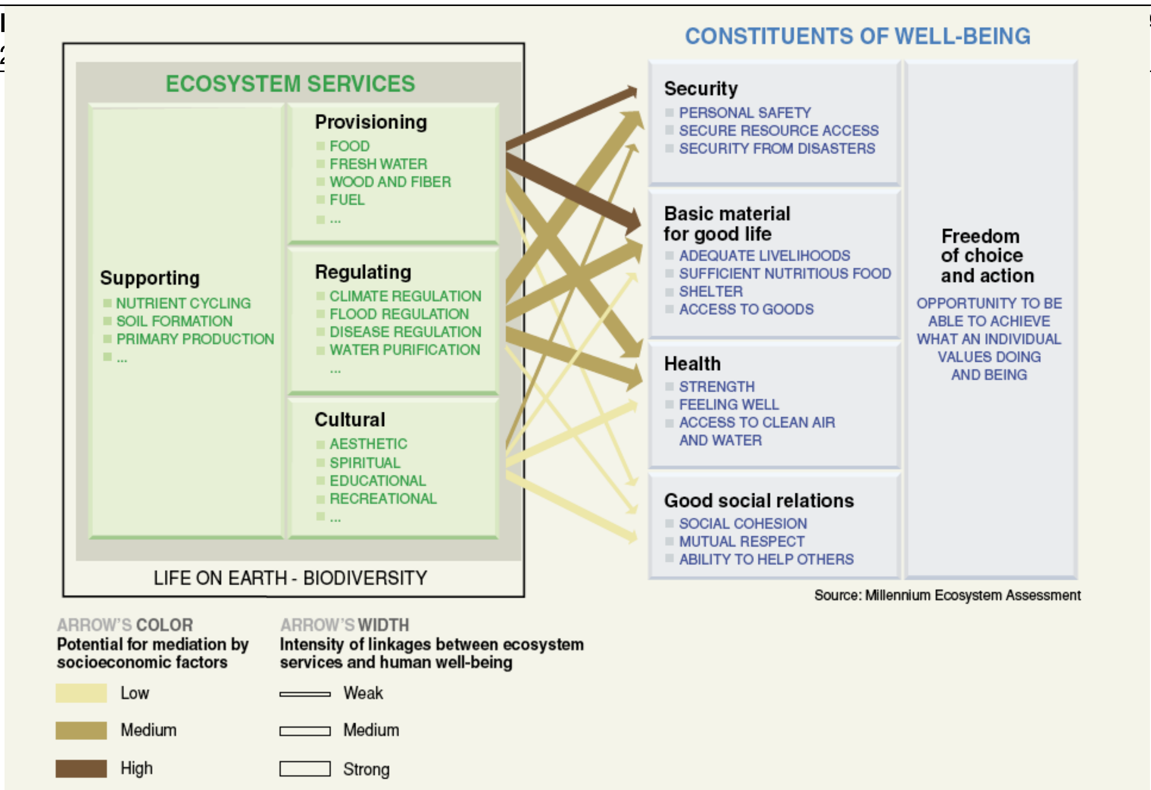
There is a significant and rapidly growing body of literature on biodiversity change in the biological sciences and on adaptation to climate change in the social sciences, but there is a major gap in knowledge on human adaptation to biodiversity change and the consequences for human welfare, vulnerability, adaptation and resilience. There are some indicators that awareness of the need to understand how humans adapt or may adapt to biodiversity change is growing. For instance, the Royal Society (the United Kingdom's national academy of science) in a report stemming from an expert meeting entitled 'Biodiversity–climate interactions: adaptation, mitigation and human livelihoods," proclaimed:

> A significant new research effort is required to improve understanding of the role of biodiversity in earth and climate systems, the impacts of climate change on biodiversity and human populations, and their inter-linkages, feedback mechanisms and cross-scale effects…To raise the profile of biodiversity within the cli-

1 According to the Millenium Ecosystem Assessment, "For the purposes of assessing progress toward the 2010 targets, the Convention on Biological Diversity defines biodiversity loss to be "the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional and national levels" (CBD COP VII/30). Under this definition, biodiversity can be lost either if the diversity per se is reduced (such as through the extinction of some species) or if the potential of the components of diversity to provide a particular service is diminished (such as through unsustainable harvest). The homogenization of biodiversity—that is, the spread of invasive alien species around the world—thus also represents a loss of biodiversity at a global scale (since once-distinct groups of species in different parts of the world become more similar) even though the diversity of species in particular regions may actually increase because of the arrival of new species" (MEA 2005).

mate change debate and to encourage decision makers to consider biodiversity, climate change and human livelihoods together…To consider the interactions between human livelihoods, the biosphere and climate in terms of functions and impacts…To consider the role that maintaining and managing biodiversity can, and should, play in climate change adaptation and mitigation strategies; and…A stronger evidence base is required to demonstrate the linkages between each area across a range of temporal and spatial scales. Further sub-global assessments are required that look specifically at the interactions between biodiversity and ecosystems, human livelihoods, and climate change…The interactions between human livelihoods and biodiversity (at the local, national and international scale) require further investigation. In particular, improved understanding of the impact of policy on the way communities interact with biodiversity will enable the development of climate change adaptation and mitigation policies that support biodiversity and development objectives…Integrated research into the factors that determine vulnerability and their interactions is required to inform the development and implementation of adaptation and mitigation programmes (Battarbee et al. 2007).

First of all and foremost, these recommendations and others, such as those of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change (CBD 2009), highlight the fact that most scientific research and policies dealing with adaptation to global environmental change focus on climate change without sufficiently considering biodiversity. The Millennium Ecosystem Assessment posited that most climate change effects will be felt through their impacts on ecosystem functions and services, which are in turn regulated by biodiversity. The MEA framework presented in Figure 1 represents "life on Earth' as a box that encompasses ecosystem services; biodiversity affects ecosystem functioning at conti-



nental and ocean basin scales, and impacts many other planetary boundaries such as carbon storage, freshwater, nitrogen, and phosphorus cycles, and land systems (Rockström et al. 2009).[2] Climate change will severely affect biodiversity, raising the probability of crossing critical thresholds; avoiding such thresholds appears to depend to a great extent on the degree to which biodiversity continues to provide for ecosystem resilience. Biodiversity change is not only caused by climate change: there are a multiplicity of anthropomorphic, drivers that until recently have had little to do with climate change (habitat loss, fragmentation, over-exploitation, invasive species, and pollution); biodiversity change is the outcome of the synergies between these drivers as well as human responses to such change.

Biodiversity change includes mass global and local species extinctions, change in species' range and phenology (timing of flowering, reproduction, etc.), and subsequent changes in ecosystem functions and services. The sixth extinction of species on the planet is underway, and the rate of extinction is probably accelerated at least 100 fold over those occurring millions of years ago. Most experts agree that climate change will soon surpass habitat loss and fragmentation as the principle driver of these extinctions (Thomas 2004, Hannah et al. 2005, Mace et al. 2005, van Vuuren et al. 2006). Climate change will also cause large-scale and widespread changes in species' physiology, phenology, and distribution, where changes in the latter have been very rapid over the past few decades and will increase with altered temperature and precipitation regimes, which will accelerate over time (Lovejoy and Hannah 2005). Changes in species' range are considered to be highly disruptive since they are expected to affect most species, communities, and ecosystems in very unpredictable ways. Extinctions and range changes lead to changing species richness, abundance, and composition in ecosystems, which leads to major changes and disruptions in ecosystem functioning and services (Chapin et al. 2000, Lovejoy and Hannah 2005).

1.2 Inattention to autochthonous human adaptation to biodiversity change

The human species will have to respond to these changes. Responses can be positive (adaptive) or negative (mal-adaptive) for human welfare and for remaining biodiversity and ecosystem services, as well as for climate change at different spatial and temporal scales. Such changes in biodiversity will have negative consequences for all human populations, but the implications are particularly dire for those living in regions where biodiversity change is expected to be greatest (tropical forest, tropical woodland, savannah, and warm mixed forest) (van Vuuren et al. 2006), and for those who directly depend on biodiversity for their livelihoods and cultural integrity, including farmers, fishers, pastoralists, and forest peoples. Massive loss of traditional crop varieties and of wild flora and fauna that provide many people with shelter, fuel, fibre, medicine, and most other life necessities is by now certain. Especially direct use values (material goods and income), indirect use values (ecosystem services), and option (insurance) values will decline, thus undermining the main source of resilience and livelihoods for people affected by all kinds of additional shocks and stresses (Salick et al. 2007). Even small changes in local biodiversity can lead to major threats to food supply and to the availability of fuel, medicine, fibre, construction materials and other plant and animal derived resources. Such changes will interact with other biodiversity stressors such as over-harvesting, invasive species, habitat destruction, and chemical pollution, all of which may push particular socio-ecological systems over thresholds. Biodiversity change will affect each region and sub-region differently, but humans will have to adapt across all major world biomes and productive systems.

The lack not only of scientific research, but of *scientific curiosity* about human adaptation to biodiversity change means that both scientists and policy makers lack mandates,

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2 Rockström et al (2009) argue that biodiversity provides 'ecological functions that support biophysical subsystems of the Earth, and thus…the underlying resilience of other planetary boundaries' (p. 18).

conceptual frameworks, knowledge, and tools to project or predict human responses and their actual or potential outcomes, synergies, and feedbacks in terms of human welfare, biodiversity, social-ecosystems, and climate change mitigation or adaptation or to support autochthonous adaptation by attending especially to those factors that can been shown to impede it. It is hypothesized that there are several possible reasons for this. The first is that biodiversity change has been overshadowed by climate change on the scientific and policy making agendas, leading the Secretary to the Convention on Biological Diversity to make a plea in April 2008 for biodiversity loss not to become 'a poor cousin to the issue of climate change' (UNPFI 2008)3. In December, 2008, the recommendations of the 9th National Conference on Science, Policy, and the Environment 'Biodiversity in a Rapidly Changing World' of the U.S. National Council for Science and the Environment (NCSE) reported:

> Twenty years after national biodiversity legislation was first introduced in the US Congress, political support for protecting life's diversity remains minimal. There is considerable interest in protecting elements of biodiversity – charismatic and endangered species, agriculturally important genotypes, and spectacular and attractive ecosystem types. Despite scientific understanding of the interconnectedness of life, the challenges of even thinking about conserving the totality of genes, species, ecosystems and evolutionary and ecological processes and phenomena is daunting. Ironically, rapid global climatic disruption, now the greatest threat to biodiversity, has pushed biodiversity even further off the public and political agenda. Meanwhile, biodiversity continues to decline at an alarming, but generally unrecognized rate.4

This also hints at a second reason for the lack of attention to human adaptation to biodiversity change, which is the predominance of conservationist approaches to biodiversity management that exclude humans from consideration either by concentrating on so-called non-human dominated ecosystems ('pristine' environments), or by considering humans to be destructive of biodiversity, and thus inimical to conservation efforts.

The third reason may be that there are few sciences and scientists focusing on human-biodiversity relations directly, and these have little influence in scientific agenda setting or policy making. The social scientific disciplines most directly concerned are the ethnosciences (e.g. ethnobiology, ethnobotany and related), human ecology, historical ecology, and geography (e.g. Conklin 1954, Ellen 1981, Rappaport 1984, Posey 1985, Descola 1994, Denevan 1995, Zimmerer 1996, Berkes 1999, Scoones 1999, Moran 2000, Marten 2001, Alvard 2002, Abel and Stepp 2003, Sutton and Anderson 2004, Dove et al. 2005, Balée & Erickson 2006, Lansing 2006, Atran and Medin 2008, Howard et al. 2009) and, to a lesser but important extent, ecological economics. Added to this are applied natural science sub-disciplines such as agroecology, agroforestry, and crop genetic resources that focus on ecologically complex and biologically rich production systems that are generally managed by traditional peoples (e.g. Brush 1995, Gliessman 1998, Leaky 1998, Altierri 1999, Heywood 1999, Altierri 2000, Sastrapradja and Balakrishna 2002, Vandermeer 2002, Clement and Shrestha 2004, Kumar and Nair 2006, Perrings et al. 2006, Jarvis et al. 2007, Verchot et al. 2007). All of these disciplines have made major contributions to a profound shift in understanding of human-biodiversity/nature relationships over the past few de-

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3 United Nations Permanent Forum on Indigenous Issues (UNPFI). 2008. Statement by Dr. Ahmed Djoghlaf, Executive Secretary, Convention on Biological Diversity, Opening Press Conference for the 7th Session of the UNPFII. Theme: Climate change, bio-cultural diversity and livelihoods: the stewardship role of indigenous peoples and new challenges. UN Headquarters, New York, 21 April 2008. Sp-2008-04-21-un-en-pdf.

4 Conference DRAFT Recommendations: 9th National Conference on Science, Policy, and the Environment: *Biodiversity in a Rapidly Changing World*, Dec. 8-10, 2008. Online at: http://www.ncseonline.org/Conference/Biodiversity/Recommendations/Microsoft%20Word%20-%20Breakout%20Recommendations%20v4%20edited%20draft%2001.28.pdf

cades, and some of the key insights from these disciplines are presented here. Nevertheless, within these disciplines, there is as yet scant attention given to biodiversity change.

The fourth reason is related to the fact that most of the research to date that deals with adaptation to biodiversity change, or to climate change and biodiversity, focuses on measures that can be implemented on a large scale, and most are related to developed countries or temperate ecosystems. These are science and policy-driven, top-down recommendations or interventions that seldom consider how humans do or might respond either to such interventions or to climate change 'from below'. A few excerpts from a recent review of such literature for the CBD's AHTEG on Biodiversity and Climate Change (Campbell et al. 2009) are illustrative of some of the difficulties:

> The impact of [climate change] adaptation strategies on biodiversity has been shown to be negative in many circumstances…the role of biodiversity in adaptation has received little attention at the scale of national and international adaptation policy…particularly in developing countries…There needs to be greater consideration of synergies and trade-offs in adaptation policy and planning, including improved understanding of the underpinning role of biodiversity…The viability of the many different options available for adaptation in agriculture is dependent on the availability of financial human and natural resources and on the willingness of farmers to consider the options…most of the management practices suggested to date [for forestry] have been generic and based on temperate case studies…there are significant socio-economic and political barriers to mainstreaming adaptation into sectoral forest policies…although integration across sectors [e.g. water, health, agriculture, forestry, climate change, etc.] is preferable, including the integration of environmental measures, this will require significant institutional capacity. Integrating natural resource management into adaptation in particular requires considerable institutional support, and this is currently lacking. Linkages are rarely made between adaptation policy and issues of governance and land tenure, which are key in developing adaptive capacity to manage resources…the effective participation of local communities in adaptation strategies are [sic] likely to be a key determinant of the integration of biodiversity into adaptation (pp. 2-3, 6-7, 19, 22, 23).

It is argued below that rural subsistence populations are the priority group that must be addressed when considering the global and local implications of human adaptation or mal-adaptation to biodiversity change, and it is these population groups that are least likely to benefit from biodiversity adaptation policies or interventions, should such policies and interventions ever be implemented. Often, the populations that should be prioritised in research on human adaptation to biodiversity change are portrayed as 'the poorest members of society [who]…have low adaptive capacity' (Campbell et al. Ibid). If adaptive capacity is assumed to be low, then adaptation depends on the support of scientists, policy makers, and others who intervene and prescribe adaptation measures.

However, it is argued here that these population groups hold the key to the maintenance of at least some of the Earth's most valuable biodiversity, and possibly to the survival of the human race as a whole. How these groups *autochthonously*[5] adapt or mal-adapt to biodiversity change is thus one of the most crucial questions that is yet to be adequately framed, much less addressed, by science and policy. The importance of autochthonous ad-

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5 I use the term 'autochthonous' rather than 'autonomous', as the authors cited do below, since, while authochthonous means indigenous or native, thus of local origin, autonomous means independent, without outside control, and/or self-governing. The latter thus tends to obviate the inter-dependence between peoples on both spatial and temporal scales, and the lack of control that many otherwise autochthonous peoples exercise over many change drivers.

aptation was recently addressed in a conceptual framework on the human dimensions of climate change developed by the Commission on Climate Change and Development of the Swedish Ministry for Foreign Affairs:

> This paper presents a conceptual framework that turns the mainstream adaptation discourse upside down, with understanding and respect for autonomous adaptation as the starting point for a new agenda to manage the human dimensions of climate change. It suggests that adaptation should be built on efforts to more effectively support individuals, households, and businesses as they struggle to adapt to climate change and that this should be done with a deeper awareness of the social, economic, cultural, and political factors that frame their actions, incentives, opportunities, and limitations for action…The poor adapt in ways that are usually unnoticed, uncoordinated, and unaided by national governments, development agencies, or international agencies. People draw on resources and support from these sources, but they do it in ways that are rarely reflected in the formal mechanisms designed for poverty reduction and climate adaptation…This paper's focus on autonomous adaptation is an appeal for a new ethos on adaptation, wherein responsible governments and institutions ensure that adaptation priorities are at least informed by and where possible even set by those who must adapt. A new mindset is needed if room is to be provided for people to develop their own agendas, in concert with local and national governments (2009: 3, 6).

1.3 Responding to essential questions

What, then, are the major questions that researchers may need to address regarding autochthonous human adaptation to biodiversity change? A set of questions regarding possibilities for adaption are generally related to the ability of species and ecosystems to adapt to change, and the rate of adaptation. As climate change accelerates, ecologists and biologists are raising critical questions about the rate of species adaptation. Many biologists argue that the rate of change is now so rapid, and the constraints (e.g. in habitat fragmentation) are so great, that mass extinctions are now inevitable. Yet, while in the past it was generally accepted that species evolve only slowly, there is mounting evidence that they can evolve quite rapidly in response to disturbance or change. Further, given the degree to which the species composition of most of the Earth's ecosystems have been recently altered, it is recognized that co-evolution may also occur much more rapidly than what was formerly thought. With respect to the most adaptable of all species – the human species – we are part of this co-evolutionary process and play a major role in such ecosystems, functioning metaphorically or actually as keystone species and engineers, purposefully and inadvertently affecting species richness, composition, and interactions. Questions that arise from such functions include: How quickly can humans respond to changes in species composition and richness, and 're-engineer' ecological systems in ways that are desirable in terms of the goals of such populations? What impairs, and what facilitates, such responses, and what influences the outcome in terms of human welfare, biological diversity, and ecosystem functioning? Are there predictable trajectories of response given particular patterns of change? Are there black box variables that facilitate or impede adaptation at different scales? How are cultural values, production, livelihood systems and economic modes, institutional arrangements, knowledge, social and physical mobility, as well as ecological phenomena linked or not to human capacity to respond or adapt autochthonously to rapid biological and ecological change? What are the intended and unintended effects (emergent properties) of such responses to biodiversity and related ecosystem change? When are such changes so rapid and significant that they simply overwhelm human capacity to respond?

Human adaptations to biodiversity change are expected to include a diverse range of strategies, some of which are responses common to various types of stresses (such as drought or illness), i.e. changing land use, altering cropping and grazing practices, changing consumption patterns, liquidating assets, seeking alternative sources of income, and migration. Other adaptations are expected to be more specific, such as creating or using micro-environments to cultivate threatened or missing species, *in situ* conservation of planting materials, substituting species, and sourcing the required diversity (and knowledge) through extended social networks and/or trade (human biological corridors). Mal-adaptation is certainly expected: for example, as biodiversity derived livelihood assets diminish, pressure increases to over-exploit remaining resources; imperfect knowledge given new species configurations and ecological conditions can result in threats to health and safety (e.g. incorrect substitutions of species for medicine, food and animal fodder) and loss of productivity (e.g. failure to encounter appropriate grazing resources, incorrect planting dates, ineffective means to combat weeds and pests). Given the dearth of research, however, such examples of adaptive and mal-adaptive responses are very incomplete.

Below it is proposed that a concerted effort to understand human adaptation to biodiversity change should focus on communities affected by invasive alien species (IAS), which provide the types of adaptation challenges and insights presented in sections 2 and 5 below. IAS are a major driver of local and global extinctions and of ecosystem change. The number and magnitude of invasions have increased up to 1000 times over the past few centuries. IAS and their impacts provide 'experiments' in real time across large spatial and temporal scales that allow researchers to observe ecological and evolutionary processes and rates of genetic change that are not easily observed otherwise (Sax et al. 2007), and ecologists and evolutionary biologists are developing major insights about biodiversity change drivers and their potential outcomes for biodiversity and ecological communities by examining such invasions. There are many good reasons for giving special attention to human adaptation to IAS in an effort to understand human adaptation to biodiversity change more generically. First, invasions will continue to be an important driver of biodiversity and ecosystem change since the same drivers that have been responsible for their increase in the past will continue into the foreseeable future. Second, invasions will increase quite dramatically with climate change due to species range change: most of the world's habitats are likely to experience native species loss and to gain new species. Thus, the existing literature on IAS helps to understand biodiversity change from a biological and an ecological perspective, and provides insights that help to understand, if not predict, some of the major effects of global, regional, and local environmental change. Third, IAS provoke both changes in species (including agrobiodiversity) and in ecosystem functions and services to which humans respond in adaptive and mal-adaptive ways. There is as yet very little research on human adaptation to IAS, but the literature that exists highlights some of the important dimensions of human adaptation to biodiversity change, and is discussed in Section 5.

In the remainder of this paper, biodiversity change processes are defined and their implications discussed from a biological and ecosystemic perspective, where particular attention is given to IAS. Subsequently, attention is focused on the need to prioritise particular human populations in research and policy development. Then, evidence is presented attesting to the lack of scientific knowledge about especially autochthonous human adaptation to biodiversity change in the form of a brief review of the most important scientific citations databases. Then, a full review of the scant literature on human adaptation to IAS provides insights into processes and consequences of autochthonous human adaptation and mal-adaptation, thus illustrating the need for and importance of such research. In the final section, the outlines of a research-policy programme is proposed that can begin to address the gaps.

2. Defining and Assessing Biodiversity Change Globally

As mentioned above, the rate of species extinction is probably accelerated at least 100 fold over those occurring millions of years ago; however, in addition to global extinctions, many more species will become extinct in particular locales. Added to these very major losses of species and biodiversity globally and locally are the potentially equally disruptive changes expected in species' range (itself a major contributor to extinctions) that results from the synergies between climate change and habitat change, since these changes are expected to affect most species, communities, and ecosystems in very unpredictable ways. Each of these phenomena is dealt with here in terms of their expected dynamics, magnitudes and impacts, albeit in a very succinct and over-generalised manner. The type and nature of drivers and their interactions are important insofar as they determine to a significant extent the possibilities for mitigation (minimising change) and the needs for adaptation where changes are inevitable.

2.1 Biodiversity change drivers and species extinctions

According to the Millennium Ecosystem Assessment (Mace et al. 2005), at present habitat change and fragmentation are the most important drivers of species extinctions, whereas invasive species and over-exploitation are the next most common, and disease, climate change, and pollution follow these in importance. Until recently, scientists generally agreed that species extinctions are principally due to habitat change and fragmentation, where human-induced land use change (e.g. agricultural expansion and tropical deforestation) have been the most important drivers, particularly since species richness is highest in tropical forests. As a result, most conservation activity has focused on reducing habitat loss and its impacts (Lewis 2006). Nevertheless, the major drivers of biodiversity change vary per biome. For example, in tropical forests, habitat change has had a very high impact on biodiversity over the past century, followed by over-exploitation, whereas climate change, invasive species, and pollution have played minor roles. This is not the case in boreal forests, where nitrogen and phosphorus pollution have been the major drivers. Since the 1990s, evidence has been growing that climate change is both interacting with these drivers and is increasingly a driver in and of itself, to the point where most experts now agree that climate change will surpass habitat loss and fragmentation as the principle driver of species extinctions (Hannah et al. 2005, Thomas 2004, van Vuuren 2006). Scientists now consider that it is the synergy between habitat change, fragmentation, and climate change that is the most threatening, given that habitat loss and fragmentation can prohibit species from migrating and colonising new areas in response to climate change (Lovejoy and Hannah 2005).

Van Vuuren et al. (2006) considered the synergies between climate change and habitat (land use) change when they modelled vascular plant species extinctions under the four MEA scenarios in order to predict the effects for different world regions. Their results are, they report, conservative, because they did not take into account other drivers of biodiversity loss such as species invasions, over-exploitation, and pollution. They predicted that, 'In terms of absolute numbers of species, tropical forest, tropical woodland, savannah, and warm mixed forest account for 80% of all plant species lost at equilibrium by 2050.' The greatest decrease in area will be found in tropical ecosystems and, because these are also highest in biodiversity, they will experience the greatest biodiversity loss. Globally, over the period 2000-2050, habitat change will be the dominant driver of extinctions given that climate change is predicted to be less important for tropical biomes, and it is these biomes that have the highest number of species. However, numerous studies now emphasise the dramatic effects that climate change is likely to have on biodiversity in one of the most important tropical regions, the Amazon, and particularly in the Amazon rainforest, where drought and fires are the major concerns and may cause massive loss of biodiversity (e.g. WWF 2006, Malhi et al. 2007).

Whereas many scientists have warned that climate change may drive certain species and ecosystems to extinction, such as in high latitudes and in neotropical cloud montane forests, models made by Williams et al. (2007) that map local climate change indicate that such climates may entirely disappear. Species that are endemic to these climates are obviously at risk of extinction, and ecological communities likewise may desegregate or disappear. The threats to biodiversity are subsequently great: 'The areas of disappearing climates closely overlay regions identified as critical hotspots of biological diversity and endemism, including the Andes, Mesoamerica, southern and eastern Africa, Himalayas, Philippines, and Wallacea' (Ibid.).

2.2 Climate change and phenology

To appreciate the full impacts of climate change on biodiversity, it is important to clarify how species respond individually and in the aggregate (on average). In the short term, phenological changes (changes in the timing of natural phenomena such as the date of leaf and flower emergence, of migrations, egg laying or insect maturation) are probably the first to occur, where plants are affected primarily by photo-period, temperature and, less commonly, moisture availability (Root and Hughes 2005). In temperate zones, such changes are related to accumulated temperature, where global warming is advancing the timing of seasonal events such as budburst and is delaying autumnal events such as leaf fall, giving rise to a longer growing season. Higher latitudes and higher elevations experience greater change. In the tropics, phenology is more related to precipitation, where an increase in the length of the dry season will have major consequences for plants. For example, plants may fail to flower or flowering may not be synchronised, and insect populations may be higher during the phase of main leaf growth (Ibid.).

Insects and mammals are likewise affected and the effects on these species in turn have major implications for plants, plant communities, and agriculture. Insects and cold blooded animals may become adults more quickly, which can result in more generations per year; flying insects might fly earlier, and so locate mates, disperse, avoid predators and lay eggs more easily. Many insectivores may find more food sources earlier in the year, so their population numbers may increase. Certain migratory species may find that their foods supplies are unavailable at the accustomed moment or in the accustomed place, which may pose a major threat to temperate species that over-winter in tropical areas (Ibid).

2.3 Species range change and habitat fragmentation

> As the globe warms, animals will probably shift both their ranges and densities. Species will be able to move into regions that are warmed, and retreat from areas that become too warm...but this will be species-specific...This differential shifting could easily cause a tearing apart of present-day communities, resulting in an uncoupling of predator-prey interactions and reequilibration of competitive interactions (Ibid.).

This highlights a subject that is of great concern to biologists and ecologists: the uneven ability of species to change their range, or distributions, in response to climate change, which many scientists think represents one of the main means that species have to adapt given that climate change is occurring too rapidly to permit many species to evolve *in situ*. If individual species are not able to change range in response to changes in temperature or precipitation, they are likely to be lost. It also highlights a second major concern, which is the breakup 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.

Throughout biogeographical history, climate change has continually transformed biodiversity, resulting in evolution *in situ* of individual species, changes in species distributions in time and space, and in associations between species with concomitant changes in species communities and ecosystems. Some biologists consider that species survive in what environmental or climate 'envelopes' - the temperature and moisture regimes to which they are adapted physiologically. Since the 1980s, they have been building models that use climate envelopes and data on individual species (physiology, current distribution) and ecosystems to estimate future extinction rates in different areas of the world, as well as changes in species range (actual as well as projected) (e.g. IPCC 2001, Malcolm et al. 2005). Meta-analyses indicate that temperature rises in the 20th century have led to shifts in species' range toward the poles that average 6.1 km per decade (Williams et al. 2007). In the past, the climate has changed rapidly and biodiversity has changed on a par with relatively few extinctions, but today habitat loss greatly constrains the capacity of species to adapt through migration (Hannah and Lovejoy 2005). Species with high dispersal capabilities may migrate at the rate of one kilometre per year or more and it is these species, together with climatically tolerant species, that are likely to dominate many of the earth's ecosystems. Other species, such as forest herbs and earthworms, may migrate at rates of less than 10 m/yr. These processes of migration, colonisation, and local extinction also occur at different rates: some species may persist for a substantial amount of time in an unfavourable environment before becoming extinct, creating a substantial lag time before the full consequences are felt.

Scientists also argue that species are less able to adapt to 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 results in a reduced capacity to migrate (Thomas et al. 2004). Both biodiversity loss and changes in species range can have multiple knock on effects on ecosystems, which may be drastically altered in large part due to changing species composition and richness, which in turns affects ecosystem functions and services. Many researchers emphasise that there is a lack of knowledge as well as inherent difficulties entailed in attempting to predict such changes (e.g. Williams et al. 2007, Battarbee et al. 2008).

2.4 Insights into biodiversity change from Invasive Alien Species

An 'alien' or 'exotic' species is generally regarded as a one that has been introduced or established because of human activities. 'Invasive' generally implies that an alien species has become naturalised, that is, its populations have become self-sustaining (Sax et al. 2007). The MEA defines IAS as 'those species introduced outside their normal area of distribution whose establishment and spread modify ecosystems, habitats, or species, with or without economic or environmental harm' (Mace et al. 2007).

Assessing the human and ecological impacts of IAS is both complex and important, and the insights to be derived lead to recommendations for researching the dynamics of local native species decline. Sax et al. (2007) review much of the relevant literature, drawing out the implications for the understanding of native species extinctions, adaptation, and climate change impacts. First, they note that it is often assumed that ecological communities are saturated with species and new species cannot be added without losing existing species: a corollary is that, if areas are species rich, they will be more resistant to invasion. However, whereas studies of birds on islands provide strong support for saturation, many other studies show that many communities are not saturated and that the net outcome of species invasions is usually an increase in species richness. This implies that biodiversity will not necessarily decline even when new species colonise; however the direct and indirect values of biodiversity may alter substantially with changes in species and in ecosystem functions and services.

Second, the concern with IAS is often centred on the idea that it is competition between species that leads to native species extinctions. Recent reviews indicate, however, that IAS are not likely to provoke global extinctions even if they do destroy local populations. On the other hand, there are many cases where exotic predators and pathogens have led to native species extinctions, so it is important to include predators and diseases, in addition to abiotic factors such as facilitation (interactions between species that benefit at least one of the species and do not harm the other). What is not clear, however, is whether competition-induced extinctions are underway but are not yet evident, since this may take hundreds to thousands of years.

Third, the formation of ecological communities may often occur through mechanisms other than co-evolution, based solely on ecological interactions among species. Some communities are composed mainly of exotic species and these communities can be as rich as those that are dominated by native species. It is not necessary for species to have co-evolved, since 'rapid evolutionary adjustments might still have occurred over timescales of decades to centuries' (Ibid.). This highlights a fourth insight, which is that genetic adaptation can occur rapidly (within a few years) as is seen in laboratory conditions and in relation to insect resistance to pesticides, as well as in natural field settings where human influence is low. Sax et al. (Ibid.) note that severe population bottlenecks do not necessarily halt rapid adaptation and cite genetic mechanisms through which population bottlenecks might promote adaptive responses. These insights are very important for conservation initiatives: researchers are increasingly questioning whether conservation biologists might not be impeding rapid genetic adaptation when they make deliberate attempts to maintain genetic diversity within managed populations.

Finally, Sax et al. (Ibid.) indicate that climate envelope approaches may be inadequate to project future distributions of many species, since native distribution 'results from the combined effects of abiotic environmental conditions, species interactions and dispersal limitation,' but it is usually difficult to determine how such variables operate independently or interactively. Climate envelope modelling might not be appropriate for estimating responses of species that have small native ranges given that some such species have small native geographical distributions but large naturalised distributions, 'suggesting that they tolerate climatic conditions different from those experienced in their native ranges', and some species with large native ranges are found 'well outside their predicted climate envelopes in their naturalized ranges' (Ibid).

Didham et al. (2007) provide an example of the importance of interactions between two major biodiversity change drivers: habitat change and IAS. They note that these two drivers are usually studied independently without researching their interactions. They develop a framework to help identify and discriminate between two very different causal pathways through which such multiple drivers interact and draw out the implications for conservation management. There is a strong correlation between habitat loss and invasions, which makes it difficult to understand why native species decrease. Habitat modification may drive an increase in the area or intensity of invasion, where the impact of the invaders increases in direct proportion to their abundance. This can occur in a linear or non-linear fashion, depending on the context and the species. Non-linear increases may indicate that even a small increase in habitat change may lead to a major change in invader abundance. In other words, there may be a lag time, and conservation efforts need to recognise that invaders that have not yet caused major impact may well do so in future. Another, distinct process, is where habitat modification changes the functional response of IAS, so that the total impact is disproportionate to IAS abundance (a functionally moderated process). These different types of interaction have different consequences for conservation.

An increasing number of studies show that the impacts of IAS are functionally mediated. For example, functional modifications may occur through changes in predator-prey relations in disturbed landscapes. It is not always the case that functional changes lead to greater IAS abundance, since there are cases where IAS have moderated the effects of habitat change. Such cases may actually be quite important, given that exotic species dominate many land use systems across the globe. Finally, they note that not all functional modification effects involve synergies: habitat modification may also mitigate the effects of habitat disturbance on IAS impacts. For example, in New Zealand, when water was extracted for agricultural use, the native round-head fish *galaxiids Galaxias anomalus* was able to co-exist with the invasive brown trout *Salmo trutta* because the trout are substantially more sensitive to low water flow conditions.

The case of IAS shows that biodiversity change is fuelled by multiple drivers that lead to increasing reconfigurations of species (disaggregation of communities). The need to understand the interactions and their dynamics is even more important when additional drivers are involved. Biologists are not accustomed to incorporating human responses into such studies of IAS, and yet it is human understandings of such relationships, their abilities to distinguish and monitor them, and their collective and individual desire and capacities to change them or not, that are likely to have the most important repercussions not only for human welfare, but as well for biodiversity and related ecosystem change, as is shown in Section 5.

3. Human Adaptation to Biodiversity Change: Which Humans?

Human adaptation to biodiversity change is clearly a very large domain of inquiry. It has been argued above that, for various reasons, Invasive Alien Species provide a good starting point for understanding human adaptation to biodiversity change. However, another major question that arises given the size and complexity of the domain is whether there are also priority human populations that should become the subject of study. There is much scientific basis that would permit prioritisation of specific types of population groups on the basis of (a) the direct importance of biodiversity for livelihoods and human welfare; and (b) the importance of particular human populations for biodiversity management and mitigation of loss of biodiversity and of associated ecosystem services.

It could be argued that the most important human populations in terms of mitigation of biodiversity loss are the wealthy consumers of the North and South who are embedded in economic and cultural relations that drive consumption beyond planetary limits. Undoubtedly, their consumption patterns will continue to drive most of the loss of biodiversity on the planet, and the consumption patterns of these populations will be greatly affected by biodiversity loss. The economic and cultural processes that drive such processes can be considered as generally mal-adaptive from an evolutionary point of view; studying such processes and finding adaptive policies and forms of governance is the subject of much scholarly and policy attention (e.g. how to change meat or energy consumption patterns). Definitively, how such populations adapt and mal-adapt to biodiversity change must and will become the subject of substantial attention since biodiversity change will profoundly affect Northern economies, ecosystems, and consumption possibilities.

If, however, the aim is to focus attention on those human populations whose welfare will be most profoundly affected by changes in biodiversity change and ecosystem services, and who at the same time are responsible for the maintenance, rather than the destruction, of much of the Earth's biodiversity and agrobiodiversity, priority must be focused elsewhere, on largely subsistence based rural populations, including indigenous peoples, subsistence farmers, and ethnic minorities, which the FAO estimates at 1.4 billion rural families, or about 2 billion people. Over the past five centuries, such societies have been attempting to adapt to a vastly changing globe. Many have been subjected to brutal forms of colonialism and have disappeared as a result. However, in many places, such as parts of the Andes, Indonesia and the Philippines, the North of North America, the Yucatan, in mountainous areas of Nepal, the Indian tropics, outer Mongolia, the deserts of Northern Africa, the savannah and highland landscapes of Kenya and Tanzania, and in many other places across the globe, colonialism largely failed to very substantially alter these peoples' ways of life, testifying to their great resilience.

Many of these same peoples were subjected to the imperatives of 'modernization,' including the need to generate surpluses for rapidly growing urban populations and for foreign exchange, so the extraction of their raw materials and the conversion of their lands for agriculture, cattle ranching, plantations, and so forth occurred on unprecedented scales. During the effort to revolutionize agriculture through Green Revolution technologies, many of their production systems were characterized as 'backwards' and 'low yielding' and, at worst, 'environmentally degrading'. The people themselves were seen to be in need of cultural assimilation and development so that they could eventually become equal to the educated citizenry of their own capitols or of the North. Even as the 'decades of development' lost impetus and the accompanying ideologies began to die out, with the emergence of integrated rural development and anti-poverty approaches, most of the people living in rural subsistence societies were portrayed as the 'world's poor' who are in need of the benefits of Western science and of global economic growth. Underpinning this is the idea, which still prevails in most policy circles today, that such people's cultures and production systems are impediments to progress and to the eradication of poverty.

However, with the growing realization that global markets are largely failing to reach or support many of the worlds' rural subsistence households and communities, and that global technological solutions such as modern crop varieties and chemical inputs very likely do more damage than good to their ecosystems, productivity, and diets, a strong new current of thinking has emerged, which is that these people and their production systems are largely functional and sustainable, and indeed are globally important (e.g. Howard et al. 2009). Over the past few decades, it has been recognised that they harbour a form of wealth that is rapidly becoming the most valuable on the planet, which is the vast majority of the world's agrobiodiversity, and of its largely sustainable agroecosystems, which are very well adapted to the conditions in which these people live and which are increasingly seen as essential resources with which the rest of the globe may be able to confront and mitigate extreme loss of biodiversity (see e.g. the Japanese/UNU Satoyama Initiative; the FAO's Globally Important Agricultural Heritage Systems Programme).6 Aside from genetic wealth, they are also recognised to contain a wealth of resilience in the form knowledge, as well as institutional, linguistic, and 'biocultural' diversity (e.g. Maffi 2001, Smith 2001, Moore et al. 2002, Pagel and Mace 2004, Maffi 2005).

This paradigm shift in thinking has emerged in large part due to the struggles of these same peoples to retain their ways of life and to defend their human rights, and because many scientists have come to realize that, in spite of an immense wealth of scientific knowledge, we seem to know very little about how to live in and with the natural world, and much less about how to tell other cultures how to go about doing this. At this moment, many are seriously questioning whether the 'end-point' of 'development' might not be the wrong one. At a global level, scientists are coming to realize that we need to retain the tremendous adaptive capacity, knowledge, and cultural resilience that have allowed the human race to come to occupy and thrive in virtually every ecosystem on earth over a long period of time, and are becoming conscious that places and things of great beauty, harmony, and intrinsic value are likely to disappear and to recognise the need to maintain options for the human race, given that our great experiment of 'development' may possibly fail. If we are to do anything about the greatest loss that humankind has ever had to confront – the loss of biocultural diversity on Earth – this requires a very different way of thinking, and a very different approach to those that conventional development thinking and conventional sciences have to offer (see e.g. Howard et al. 2009).

6 For the FAO GIAHS Programme, see http://www.fao.org/nr/giahs/en/and for the Japanese Government/United Nations University Satoyama Initative, see http://satoyama-initiative.org/en/

Scientists who are concerned with these issues call for a holistic approach. Biologically diverse human dominated subsistence systems cannot be characterized as agricultural systems or agroecosystems; they are not places or practices; they are not people; and they are not ideas. They are social-ecological systems that are made up of the interaction of all of these things: people, places, biological organisms, abiotic substrata, technologies and infrastructure, practices, knowledge, and ideas. They are not the product of industries, markets, science, or policies, or of ministries, development agencies, or NGOs. They are the product of *cultural evolution*: that is, of the cumulative knowledge, experience, ideas, and ways of organizing society and ecosystems that have been built up and adapted over centuries or even millennia (Alvard 2003, Richarson and Boyd 2005). They represent above all the ways that people have met all of their cultural and material needs over time principally on the basis of local biological resources. They are best called social-ecological systems because this term best captures the co-evolution of humans and nature – how humans have shaped the natural world and developed organisms to meet their needs, and in turn how human culture, including religion, values, norms, knowledge, and social relations have been shaped by the ecosystems in which they live.

These systems are not ‘primitive’ or simple, but rather are sophisticated and complex. Their stewards may be illiterate but they certainly are not ignorant: it takes an average person living in such a society at least a third of a lifetime to accrue the minimum knowledge necessary just to support a household, and a specialist (for example, in medicines, or in the diversity of specific crops, in religion or a political position) may require two-thirds of a lifetime to learn what she or he must know to be considered as truly learned and capable. These societies are based upon a very complex set of laws and behavioural norms, as well as webs of social relations. People in these societies generally don’t use markets to tell them how to produce, procure, and exchange goods, and yet they have managed not only to procure and exchange goods within their social-ecological systems, but as well with nearby and far flung peoples. They generally don’t have written legal codes, but they do know who has access to what, when, and how, and they pass these rights and duties along when people die; they also have managed their common resources so that these are not over-exploited by the few, and provide the means of subsistence for virtually all people within them and, at least until recently, on an environmentally sustainable basis. They don’t have access to laboratories, or to GIS, or to libraries, or the internet, and yet they continually experiment, innovate, and adapt their knowledge, techniques, and practices to changing environmental, economic, and social conditions. They don’t have formal education and yet manage to transmit the knowledge accumulated over centuries to their children. They don’t have museums, or heritage laws, or zoning or planning ordinances to preserve their buildings, temples, and sacred groves, and yet they manage to transmit their cultures, their arts, architecture, and sense of aesthetics generation after generation, changing these, it is certain, but without losing their sense of identity or cultural continuity over time.

No one who does not belong to these cultures or systems can re-engineer them, conserve them, or otherwise adapt them. Outsiders cannot possibly have the knowledge, skills, or motivations to maintain dozens to hundreds of local varieties of a single crop, or identify, process, and administer hundred of plant species as medicine, or govern their complex irrigation networks or replace their complex sets of rules about when, how and where to hunt, fish, and exploit and manage wild plant resources. Most outsiders can’t even speak their languages. The only people who have the knowledge, skills, motivations, and perseverance to do so are those who have inherited them and who are living their lives trying to pass them on to their heirs; this is the axiom that underlies the myriad of calls for ‘local participation’, ‘local knowledge’, and respect for local systems of rights and governance, such as those attributed to the 2009 Nobel Prize winner in Economic Science, Elinor Ostrom (see e.g. Cleveland and Murray 1997, Anderies et al. 2003, Ostrom 2004). Such systems have and continue to represent the resilience of much of the human species, as well as the best future hope for at least a very substantial part of it, and they contain a very large part of the wealth that the rest of humanity and the planet's ecosystems require more than ever before. Very possibly they will only remain such if science and policy makers recognise their value and need for relative autonomy and support them by mitigating negative change drivers as possible, allowing the people who live in these systems to maintain the resilience of their cultures and their ecosystems given so many threatening drivers of change.

A scientific agenda on human adaptation to biodiversity change thus should focus first and foremost on rural subsistence societies and on the ways in which these population groups autochthonously adapt or mal-adapt to biodiversity change. The emphasis on autochthonous adaptation is well justified insofar as (a) most of these population groups in the past have been barely supported by external agents, and in future are likely to remain unsupported in their efforts to manage their social-ecological systems, and thus their responses to biodiversity change will largely be autochthonous; (b) their autochthonous adaptations or mal-adaptations have major implications for mitigation or accelerating biodiversity loss and for the welfare of those who have minimal access to alternative resources; and (c) knowledge about such adaptation and mal-adaptation can be used to assess likely future outcomes for biodiversity and human welfare, as well as provide a much broader set of potential adaptation strategies and knowledge about their impacts (intended and unintended) that could indeed be used to support human adaptation and biodiversity change mitigation efforts more generally, much as contemporary scientific understandings of agroforestry and agroecology and the prescriptions for mitigation and adaptive strategies are based on the study of rural subsistence systems.

4. Current Scientific Knowledge on Human Adaptation to Biodiversity Change: An Approximation

To determine the degree to which HABC is a subject of scientific inquiry, a rudimentary analysis was carried out on existing (as at October-November 2009) citations in the most relevant bibliographical databases dealing with environment, biodiversity, and human populations (Set A)[7], as well as from the ISI Web of Science. In general, the number of citations found in Set A was higher (and thus more comprehensive) than the number found in the ISI database, with some notable exceptions. There are two questions to address in this context: first, 'What scientific attention is directed toward biodiversity change compared with climate change, and what is the overlap between the two?'; and, second, 'Within each of these domain sets, and in the juncture of these domain sets, what attention is given to human adaptation?'

Table 1 presents the overview of the search terms and datasets. Search terms were selected that are meant to directly address the questions just mentioned. A very large number of alternative search terms could have been used as proxies: for example, instead of biodiversity loss, terms such as species extinctions, genetic (or crop diversity or agrobiodiversity) erosion, deforestation, etc. would have almost certainly resulted in a higher total number of citations, and this is one of the first tasks that a research programme should undertake.

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7 These included: Biological Abstracts, AGRIS (the international information system for the agricultural sciences and technology of the Food and Agriculture Organization of the United Nations - FAO); AGRICOLA (the US Department of Agriculture's National Agricultural Library citations database for agriculture); CAB Abstracts (the Commonwealth Agricultural Bureau's citations database on agriculture and the environment); Zoological Record (the largest database of animal biology coverage ranges from biodiversity and the environment to taxonomy and veterinary sciences); Current Contents (most recently published issues of leading scholarly journals, as well as from more than 7,000 relevant, evaluated websites); and Tropag and Rural (published in partnership with KIT (the Royal Tropical Institute, Amsterdam) TROPAG and RURAL is a bibliographic, abstracting and indexing database that brings together the widest range of literature on tropical agriculture from the developing rural areas of Africa, Asia, the Pacific and the Americas).

Table 1. Bibliographical citations related to human adaptation to biodiversity change, Nov. 2009*

1st Search Term	2nd	3rd	4th	Records Set A	Distribution Set A (%)	ISI Records	ISI as % of Set A
Climate change				**80,564**	100.0	46689	58
“	Adaptation			**5,428**	6.7	1924	35
“	“	Human		637	0.8	302	47
“	“	Livelihoods		116	0.1	44	38
“	“	Farmers		198	0.2	91	46
Biodiversity				**160,298**		30119	19
“	Adaptation			**3,500**	100.0	461	13
“	“	Human		381	10.9	65	17
“	“	Livelihoods		31	0.9	7	23
“	“	Farmers		81	2.3	19	23
“	Mitigation			479	100.0	208	43
“	“	Human		103	21.5	38	37
“	“	Livelihoods		35	7.3	6	17
“	“	Farmers		25	5.2	11	44
Climate change				**80,564**		46,689	
“	Biodiversity			**3,847**	100.0	1866	49
“	“	Adaptation		302	5.6	107	35
“	“	"	Human	69	10.8	22	32
“	“	"	Farmers	21	10.6	5	24
Biodiversity change				245	100.0	4487	1831
"	Adaptation			6	2.4	142	2367
"	"	Human		2	0.8	30	1500
"	"	Livelihoods		0	-	5	-
"	"	Farmers		0	-	7	-
"	Farmers			8	3.3	99	1238
"	Livelihoods			0	-	43	-
"	Human			44	18.0	903	2052
Biodiversity loss				1940	100.0	2879	148
"	Climate change			207	10.7	342	165
"	"	Adaptation		19	1.0	15	79
"	"	"	Mitigation	0	-	2	-
"	"	"	Human	6	0.3	3	50
"	"	"	Livelihoods	1	0.0	1	100
"	"	"	Farmers	0	-	0	-
"	Adaptation			38	2.0	41	108
"	"	Human		11	0.6	8	73
"	"	Livelihoods		1	0.1	1	100
"	"	Farmers		0	-	1	-
"	"	Agriculture		2	0.1	4	200
Adaptation to biodiversity change				0		30	-
Adaptation to biodiversity loss				0		41	-

*Sources Set A: Biological Abstracts, AGRIS, CAB Abstracts, AGRICOLA, Zoological Record, Current Contents, Tropag and Rural (KIT)

**Citations include duplicates in Set A references in bold, but not in ISI references

4.1 Climate change and biodiversity change compared

The term ‘climate change’ resulted in 46,689 records in the ISI database (1990-current), which is more reliable than the Set A databases since duplicates could not be eliminated from the latter. Using only one of the sources from Set A (CAB Abstracts), which generally does not contain duplicates, CAB contained slightly less than half that number of citations for ‘climate change’ for the same reference period. However, ‘biodiversity’ resulted in 30,000 records in ISI, whereas in CAB abstracts nearly 40,000 and in Biological Abstracts nearly 50,000 cites were found, showing that the latter are more comprehensive for biodiversity, but less so for climate change. Such biases obviously affect the results of such an initial citations analysis. It is, however, clear that biodiversity as a domain is as least as important an area of scientific inquiry as climate change, and very likely more important if the proportions in Set A are considered, where there are twice as many references for biodiversity. However, the combination of the terms ‘climate change’ and ‘biodiversity’ in Set A resulted in about 5% of the citations for ‘climate change’ alone, and in about 4% of the ISI cites. Confirming the assessment of the Royal Society presented above, as a topic of inquiry, ‘biodiversity and climate change’ has to date received relatively little attention.

4.2 Climate change adaptation and biodiversity change adaptation compared, also considering humans

‘Climate change’ combined with ‘adaptation’ resulted in about 7% of the Set A records and 4% of the ISI records on ‘climate change’. ‘Biodiversity’ combined with ‘adaptation’ resulted in 1.5% of the cites in the Set A and ISI records on ‘biodiversity’, showing that scientific inquiry on adaptation within the domain of climate change has a stronger track record compared with adaptation in the biodiversity sciences. Comparing ‘climate change adaptation’ with ‘biodiversity adaptation’, the latter represents 64% of the records of the former in Set A and 24% in ISI. Looking at the intersection of these domains, the combination of terms ‘climate change’, ‘biodiversity’, and ‘adaptation’ produced 302 records in Set A and 107 in ISI. This represents 5.6% and 5.7% of the records where ‘climate change’ and ‘biodiversity’ are both keywords in each database, respectively, which is lower than the proportion for ‘climate change adaptation’ in Set A (6.7%), but higher than this combination in ISI (4.1%). However, it represents only 5.5% of the references found for ‘climate change adaptation’ in Set A, and 5.5% of the equivalent references in ISI, so it is very apparent that, within the climate change adaptation science domain, biodiversity is only rarely considered.

To consider whether adaptation refers to human populations rather than only to ecosystems or earth systems or species, the search terms ‘human’, ‘livelihoods’, ‘farmers’, ‘households’, and ‘people’ were combined with the other relevant search terms. In the results, the terms ‘households’ and ‘people’ were omitted because ‘people’ did not result in substantially different numbers of references compared with ‘human’, and ‘households’ resulted in substantially fewer numbers of references compared with ‘farmers’ or ‘livelihoods’. The combination of ‘climate change’, ‘adaptation’, and ‘human’ resulted in 637 references in the Set A database, or .8% of the total references on ‘climate change’, and 11.7% of the references on ‘climate change’ together with ‘adaptation’; in the ISI database, these were .6% and 15.6%, respectively. Looking at ‘biodiversity’, ‘adaptation’, and ‘human’ together in Set A, these cites represented .23% of the total references on ‘biodiversity’ and 10.9% of the references on ‘biodiversity’ and ‘adaptation’ combined, whereas the ISI database produced .22% and 14.1%, respectively. Combining ‘climate change’, ‘biodiversity’, ‘adaptation’, and ‘human’ resulted in 69 references in the Set A database, or 5.6% of the total references on ‘climate change’ and ‘biodiversity’ combined, and 22.8% of the references combining these terms with ‘adaptation’, and 22 references in the ISI database, or 1.2%

and 20.5%, respectively. The terms 'livelihoods' and 'farmers' each produced fewer references compared with 'human' in both database sets.

In general, then, while in both the climate change and biodiversity sciences the focus on adaptation is relatively slight, less attention has been given to it within the biodiversity sciences, which is also reflected in the lower total number of references found for 'biodiversity' and 'adaptation' in both databases compared with 'climate change' and 'adaptation'. Paying attention to biodiversity within the climate change (or vice versa) domain does not lead to increased attention to adaptation - only around 4-6% of such citations deal with adaptation issues, or about the same proportion of the climate change literature alone that deals with adaptation; the number of such publications is very low compared with those that treat climate change adaptation. The amount of attention given to human beings within climate change adaptation is low, at between 12-15% of the references, whereas biodiversity adaptation it represents between 10-14%, where the volume of publications on human adaptation within the combined 'biodiversity' and 'climate change' adaptation literature was somewhat higher, at between 20-23%, but the total number of references with this combination of keywords was extremely low, at only 22-69 in total, compared with the climate change adaptation-human combination, with 637 references.

The use of such keywords in combination *still* gives a distorted view of the scientific basis for assessing human adaptation to biodiversity change. The abstracts pertaining to the set of references from the Set A database that included the keywords found in Table 2 (a total of 481) were reviewed to determine which of these references were in fact relevant, screening out, for example, those that did not deal with social or economic dimensions, those that did not deal with human adaptation, or with biodiversity or ecosystem change.

Table 2. Relevance of citations on Human Adaptation to Biodiversity Change (from Table X, Set A)

Search terms† (combined)	**Total cites**	**%**	**Relevant**	**%**	**Relevance per term (%)**
Biodiversity, adaptation, human	338	70.3	35	10.4	47.3
Biodiversity, adaptation, people	57	11.9	18	31.6	24.3
Biodiversity, adaptation, farmers	68	14.1	9	13.2	12.2
Biodiversity, adaptation, households	5	1.0	1	20.0	1.4
Biodiversity, adaptation, livelihoods	13	2.7	11	84.6	14.9
Biodiversity, climate change, adaptation, human	59	12.3	10	16.9	13.5
Totals	**481**	**100.0**	**74**	**15.4**	**100.0**

†Excludes duplicates occurring between searches.

This task was difficult in part because the subject matter is still amorphous – very few references directly deal directly with human adaptation to biodiversity change. The results are presented in Table 3. First, it can be noted that only 15.4% of the references (a total of 74) were found to be relevant, ranging from 32% for references containing the term 'people' to as low as 10% of the references containing the keyword 'human'. Further, it can be argued that many of the references that were classified as 'relevant' in fact do not refer to autochthonous human adaptation to biodiversity change as discussed in this article. The references that deal with science and policy-driven adaptation to biodiversity change (29, or about 40% of the total) focus mainly on prescriptions for future actions driven by research or policy making, such as breeding crop cultivars to adapt to drought or salinity, or mapping out policies to address biodiversity loss on a national or regional scale. The scientific conceptual frameworks (10, or 13% of the total) provide valuable insights into the numerous dimensions and interrelations that must be considered at different scales, but do

Table 3. Main topics covered by relevant citations from Set A Table 2.

Relevant topics	No cites	Details
Science & policy driven adaptation	29	Especially crop breeding, governance at regional or national levels
Scientific conceptual frameworks	10	Various topics and dimensions
Calls for attention	8	Climate change-biodiversity, research, policy
Historical/paleoecological adaptations	10	e.g. adaptations to ecological niches & biological resource distributions
Local adaptations	16	Case studies of local human responses to changes, e.g. in land use, forest cover, plant species
Project-led adaptations	2	Pilot projects to promote adaptation
Mal-adaptations	8	From paleoecological to theoretical causes leading to mass biodiversity losses and/or changes in human populations

not necessarily draw upon substantial empirical data regarding how humans actually adapt or mal-adapt to biodiversity change; the calls for attention to the topic (8, or 11% of the total) contribute to raise awareness but do not necessarily add to knowledge. The bulk of the relevant references (28, or 38%) do present evidence-based case studies of local adaptations that are either indigenous or promoted by interventions (e.g. projects). Another set of references deal either theoretically or historically with the relations between human actions and major changes in biodiversity that have led (or are leading) to massive loss of biodiversity if not massive loss of human populations.

This brief review, then, shows that scientific citations databases, which yield the meager results presented in tables 1 and 2, nevertheless belie the amount of scientific knowledge that is readily at our disposal about how humans adapt, or mal-adapt, to biodiversity change. There is clearly more research that has investigated, directly or indirectly, how people adapt to changes in biodiversity given, for example, the introduction of high yielding varieties, deforestation, desertification, other types of habitat change, migration, disaster, and displacement. This literature has not yet been subjected to a meta-analysis for the purpose of gaining insights or developing conceptual frameworks. It makes it patently clear, however, that if we wish to avail ourselves of current knowledge about this topic, we must dig much deeper into the literature in order to draw inferences, which means that substantial effort must be expended to locate it, review it (meta-analysis), and effectively utilise the findings.

5. Autochthonous Human Adaptation: Insights from Invasive Alien Species

The inattention to human adaptation to biodiversity change within a subset of the biodiversity change literature that deals with IAS provides additional evidence of a major omission, *even where it has been recognised that human adaptation or mal-adaption to IAS has major consequences for both human welfare and for biological and ecosystemic change*. Much scientific and policy attention has been focused on IAS for well over a century because they are often considered to wreck environmental and economic havoc. There are currently a number of global and regional conventions and major international programmes directed toward their control or eradication.[8] The ecosystemic and economic effects of IAS have been documented in a large number of scientific publications. Great efforts are made by individuals, groups, and governments to combat IAS, which can be very expensive and which also often has a low likelihood of success, since invasions are exceedingly difficult to

8 For a list of conventions, see the European Network on Invasive Alien Species website at: http://www.nobanis.org/GlobalConventions.asp

reverse. The costs of IAS are estimated to be very high and increasing: for example, it is estimated that IAS in the United States provoke more than $138 billion per year in losses (of which an estimated US$ 21 billion is spent on control efforts), and that around 42% of the species that are listed as Threatened or Endangered are at risk due to IAS. The global cost is estimated at US$1.4 trillion, or 5% of global GDP (Pimentel et al. 2000).

What these figures generally do not reveal, however, are the implications of IAS for the livelihoods of the local populations most affected by them, who are often rural dwellers. Given a dearth of information on autochthonous human adaptation to IAS, the Global Invasive Species Programme commissioned a literature review, and carried out a rapid appraisal on the effects of IAS on poor rural households, while more in-depth research was carried out in specific localities in South Africa, results of which were published in Shackleton et al. (2007; see also GISP nd). According to their literature review,[9] economic valuations of IAS impacts focus on national or sub-national scales and primarily on ecological impacts or impacts on formal economic activities while omitting local level benefits or trade-offs. They found only four published studies that rigorously examined the role of IAS in local livelihoods. Table 4 attests to the fact, noted by a few scientists and policy makers, that this omission is untenably large. The Set A of databases was used to generate the table; however the relevant citations that actually document autochthonous human adaptation or maladaptation to IAS are much fewer, totalling about seven (the number in the ISI database).

Table 4. Bibliographical Citations on Invasive Alien Species, Nov. 2009

1st Search Term	2nd	3rd	Set A Records	Distribution (%)	ISI Records	ISI as % of Set A
Invasive species			**42614**	100.00	10372	24.4
"	Economic		928	2.18	442	47.6
“	Livelihoods		23	0.05	12	52.2
“	Farmers		157	0.37	26	16.6
“	Uses		297	0.70	124	41.8
“	Impacts	Rural	23	0.05	5	21.7

*Contains duplicates

Such studies indicate that the effects of IAS on rural livelihoods are complex; IAS often require human adaptation in the short term; they bring benefits as well as costs to rural subsistence communities, and these benefits and costs are not evenly distributed. As is the case with most wild species and landraces, many IAS provide multiple purpose resources used for food, medicine, fibre, construction, and other purposes, and they often generate income. Many have acquired cosmological or religious significance over time, and some are thought to be beautiful. IAS may be found closer to households and thus reduce the need for labour to collect these resources compared with (possibly declining) native species. Many IAS can be beneficial to some human communities at the same time that they pose costs for others as summarised in the adage ‘One woman’s weed is another’s flower’. Some households may make use of the invaders whereas others may not, or may suffer damages.

Shackleton et al. (Ibid.) conclude from their South African study of *Ficus opuntia indica* (prickly pear) and *Acacia mearnsii* de Wild. (black wattle) that ‘it is clear that the label of a ‘pest’ for an IAS is a culturally, socially, and economically specific judgement, and that the difference between ‘nuisance’ and ‘useful resource’ is perhaps a matter of perspective and scale’ (Ibid.). Which factors seem to determine the net benefits to households and communities of IAS? Contextual factors that Shackleton et al. (Ibid.) suggest influence livelihood impacts and local perceptions include ‘the extent and density of infestation, availability of alternatives, costs and mechanisms of control, land tenure, current vulnerability, discount rates, and the severity of loss of ecosystem goods’. The case study from Timor in Box 1

[9] Perrings (2005) also reviewed literature related to poverty and IAS.

Box 1. Invasive species in Timor: Livelihoods, adaptations and conflicts (McWilliams 2000).

Over the course of the 20th century, *Lantana camara*, *Opuntia elatior* (prickly pear), *Imperata cylindrica* and, most recently, *Chromolaena odorata* (siam weed) have invaded Timor with diverse effects on livelihoods that have provoked diverse adaptation strategies and responses that reveal conflicting interests in eradication. In the early part of the century, prickly pear covered 'substantial areas of grazing and farm land', at times necessitating 'wholesale relocation of settlement sites as surrounding arable land was consumed'. Its spread was probably facilitated by the fact that 'the persistence of clan warfare and feuding meant that mountain populations usually maintained barricaded defensive strongholds against attack' where prickly pear was used as a defensive barrier. Eventually, biological control agents were introduced that led to a dieback of prickly pear and today it is found only in isolated pockets. When *Lantana camara* invaded, it 'quickly established and reestablished itself following the clearing and burning of swidden food gardens. Apart from somewhat increased labor requirements for swidden clearing, most Timorese agriculturalists managed to incorporate Lantana fairly effectively into their cropping systems. Indeed, the increase in biomass and *Lantana*'s soil conditioning properties tended to improve cropping conditions and to reduce the fallow period required in swidden cultivation systems' (other research indicated that fallows could be reduced from 12 to 5-6 years in the presence of Lantana). '*Lantana*, however, was much more of a threat to cattle owners and herders. As grasslands became smothered in the unpalatable *Lantana*, extensive areas were lost to grazing resulting in cattle losses and the disbursement of stock. It also led to increase in animal numbers in the remaining *Lantana* free areas, with consequent overgrazing and soil erosion...for reasons which remain undocumented, the general incidence of *Lantana* began to decline' and by the 1980s its capacity to threaten biodiversity was largely eliminated.

Chromolaena odorata represents the largest current threat, and it began to invade Timor sometime before 1980, with 'significant adverse implications' for livelihoods. Farmers had to 'incorporate the weed into their farming systems. Few of...[its] properties were beneficial. It grows rapidly and produces a dense mass of leaf matter that gradually shades out all other competitors...[it] seems to thrive on fire..The marked and extended dry season...creates ideal conditions for the spread and dispersal' and 'In many villages up to 60% or more of the arable land is now covered.' For rural Timorese communities, cattle represent the main store of wealth, and are a vital part of social relations. *Chromolaena* is 'unpalatable and even toxic as a cattle feed, and combined with the heavy shading habit of the plant, the expansion of *Chromolaena* is in direct proportion to the decline in stock feed across the rangelands of West Timor', especially depriving animals of dry season feed. 'Local management strategies..have been severely constrained by the absence of any overall coordinated industry approach. Farmer responses...tend to be very localized and opportunistic. In the absence of any programs for improving the quality and quantity of rangeland feed stocks, and present government proscriptions on the use of fire as a management tool in the rangelands, small-holder cattle owners simply have to utilize whatever palatable feed persists into the late dry season...there is increasing competition for this restricted cattle feed supply. Grazing pressure increases and cattle are forced to subsist on ever more marginal lands and adjacent forest areas. Along with uncontrolled burning of forest areas and catchment protection zones, cattle herds are major contributors to widespread soil erosion and land degradation across the highlands of West Timor'. In spite of its purported soil conditioning properties, *Chromolaena* is also reducing maize yields due to higher labor requirements for weeding in areas where 'labor rather than land is the critical limiting resources' and due to its possibly allelopathic properties.

Imperata cylindrica, an invasive grass species, is regarded as a valuable resource, but it is being eliminated by the spread of *Chromolaena*. Young cattle are grazed on Imperata grass and it 'is the material of choice for thatch in house and granary construction'. To construct a house roof requires about 1000m2 of well-vegetated Imperata grassland, which can last up to 20 years with minimal maintenance. Alternative roof materials are corrugated iron, which has doubled in price recently and is too expensive for most rural dwellers; or palm leaf, the use of which is restricted by local availability and price...' Grain is also stored in structures that are thatched with *Imperata*. Given the loss of *Imperata* due to *Chromolaena* invasions, 'some communities are actively cultivating *Imperata* as the resource becomes locally scarce and increases in value'.

National and local government responses to each of these species invasions has generally been contrary to the interests of local farmers. In general, 'local government responses...have been muted...this lack of response is symptomatic of the lack of attention historically accorded extensive upland agriculture in Indonesia'. In spite of political pressure, the Department of Animal Husbandry has not acted, principally because it supports intensification of production through modern technologies rather than extensive rangeland production. On the other hand, the Ministry of Forestry perceives that *Chromolaena* is beneficial since it helps in the 'stabilization of critical slopes and the fertilization of eroded soils through aeration and its properties as a soil conditioner....[it] also has the indirect benefit of reducing the impact of free range cattle grazing within forest lands. Due to its unpalatable, even toxic properties due to high nitrate levels, Cromolaena provides a kind of buffer zone against cattle incursions, thereby permitting regrowth of forest seedlings. Cattle grazing in forestry lands is a significant management issue in Timor and one that often places the Forestry Department in conflict with local cattle owners'. Australian researchers have developed a management programme through biological control with the gall fly (*Procecidochares connexa*) but to date there has not been any significant success. 'Timorese farmer responses, and to a significant degree those of the local government, tend to be reactive rather than strategic, adaptive rather than interventionist, in overcoming agricultural threats'.

also shows that rural people may consider the ecosystem services provided by IAS to be beneficial (e.g. for soils) even while governments perceive them to be negative, and that ability to benefit from or control IAS also depends on labour constraints.

Shackleton et al. (Ibid.) developed a conceptual framework to help understand the possible impacts of IAS on rural livelihoods (Figure 2 and Table 5). The curves represent

Table 5. Impacts on rural communities of invasive species (Shackleton et al. 2007)

		Agressiveness	
		Low	**High**
Beneficial traits	**Low**	The species has negligible or low impact on rural people, because its invasivity is low. Hence it is easily controlled, although such control does represent a cost. It currently has no known direct or indirect use.	Undesireable, agressive species No or limited direct or indirect benefits to people. It invades rapidly, and is often difficult to control. The impacts on rural livelihoods will be most severe in the later phases of invasion. Communities are frequently unable to control the species without external help.
	High	Useful, docile species Not very invasive, the species is easy to manage. Benefits can be extracted from it, so rural people with limited livelihood options will exploit it to maximum benefit. Such exploitation will be sufficient to keep it in check in most situations.	Useful, aggressive species The species invades habitats rapidly, and may be difficult to control. It is useful to the invaded society and hence there is resistance to its complete removal. Harvesting by dependent communities is an inadequate control measure, so abundance and concomitant ecological costs increase with time.

temporal trajectories that correspond to the period subsequent to a species' introduction. The first curve plots abundance of the IAS over time in the absence of controls. The second represents local livelihood benefits that are assumed to mirror the abundance curve: the greater the resource, the greater the benefits. The third is the cost curve, which includes 'all costs, such as ecological costs, aesthetic costs, harvesting costs, costs of control, etc.,' which compound as abundance increases and therefore the curve is exponential (Ibid.). The fourth curve reflects the livelihood vulnerabilities that are related to the IAS, where vulnerabilities are assumed to be high at the beginning at the period, reducing as use of the IAS increases, and then diminishing as costs increase relative to benefits. They point out two important features related to resilience, which they define as 'a measure of the amount of change or disturbance represented by the IAS that local livelihoods could absorb without major shifts' (Ibid.). First, there are thresholds inherent in each of the curves, that is, 'points at which the rate of response over time changes markedly. Additional thresholds are possible at intersections between curves' and these thresholds are what must be identified and monitored in order to predict impacts (Ibid.). Second, the temporal dimension must also be identified as much as possible in the field. In the early stages of invasion, benefits are generally low or indirect and are confined to those who have introduced the species or to those who have first discovered possibilities for exploitation. In the next phase, abundance has increased and so have the number of people who are obtaining benefits, which 'may have prompted technological innovations or changes in livelihood patterns'; ecological costs may be approaching or surpassing a threshold, and management options may be considered, but livelihood vulnerability is generally reduced. It is in the third phase where costs generally exceed the benefits unless controls are exerted or important new benefits arise. 'People are now faced with either (1) controlling the invasion, or (2) living with it resulting in impaired livelihood options and increased vulnerability' (Ibid.). Of course, not all IAS are equal: some present only costs and others present principally benefits. The differences between IAS are presented in Table 5 as a matrix of aggressiveness and benefits, and is self-explanatory.

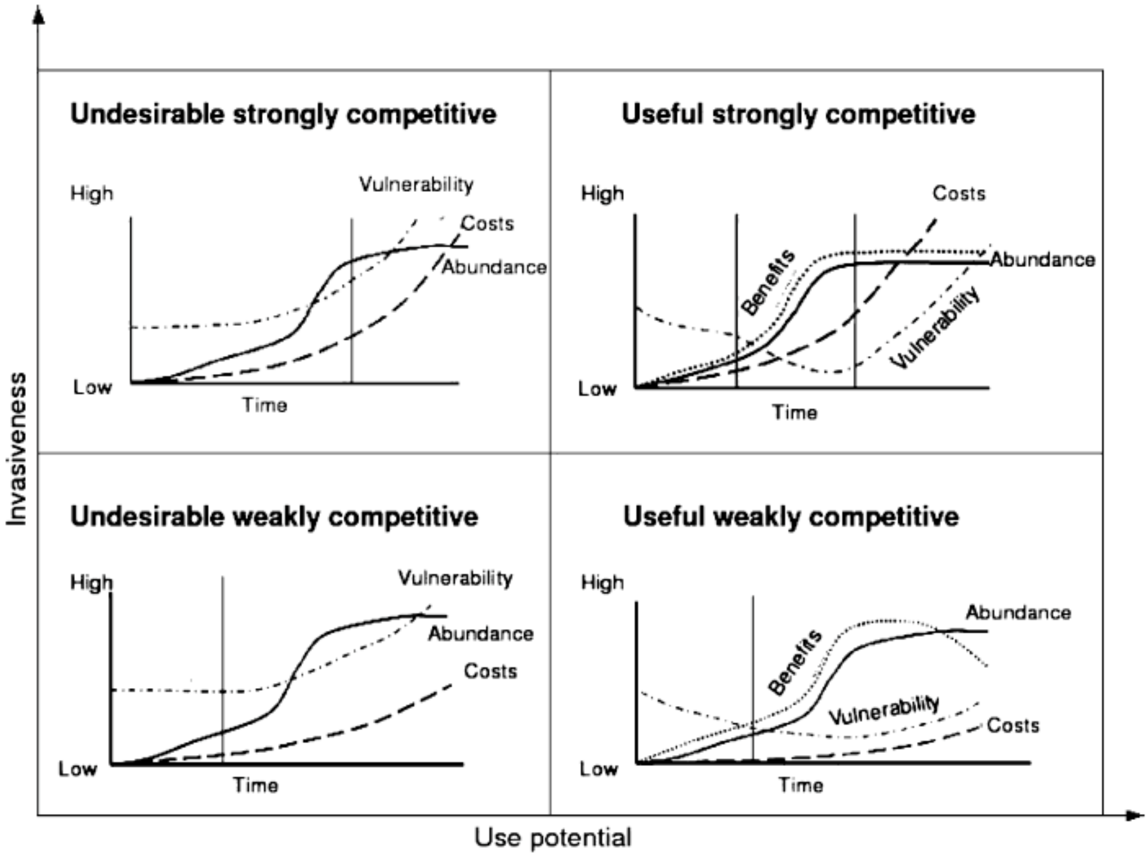

Fig. 2 Variations of the conceptual framework for different species types. (Note that the *x*-axis is longer for weakly competitive species as it takes longer for effects to occur).

Siges et al.'s study (2005) on the livelihood impacts of *Piper aduncum*, a shrub or low tree, in the Finschhafen area of Papua New Guinea, indicates how adaptation has occurred as *Piper* has come to dominate much of the landscape, having colonised most of the fallow land and secondary forest vegetation. One farmer described the changes with *Piper* invasion:

> Our forefathers cut a lot of forest trees down to make gardens in the past. All the forest and its services are gone, together with the wild animals. We only see what forest is like from the pictures in the magazines or books. *Piper* has become our new environment (cited in Siges et al. Ibid.).

Today, live *Piper* trees are used as shade for pigs, windbreaks, and weed control. Mature stems are used as digging sticks; stems and branches are used to build soil retention structures that permit cultivation of crops on contours where previously only grasses and cane were grown; stems, stumps and branches are used for staking climbing crops; stems are used to make and maintain fences, for pegs, to build chicken coops, coffee and vanilla drying platforms, and handles for tools; roots make soil tillage easier (men now establish new garden sites in areas where *Piper* dominates since it is easier to remove and soils are lighter); ashes are used as pesticides and fertilisers; and is it used as a medicinal to treat cuts, tooth-ache, diarrhoea, dysentery, cough, fungal infections, insect bites, headache, scabies and stomach ache (Ibid.).

Many older residents lament the loss of native species, particularly forest species, since indigenous forest regeneration was impeded by *Piper* invasion. They once used native trees for timber, rafters, poles and posts, which have now been replaced by *Piper*; people are no longer able to collect many wild fowl eggs, mushrooms, and rattans, and wild animals such as cassowary, pigs and other small animals no longer inhabit fallows. There has been a switch from the staple crops Chinese taro (*Xanthosoma sagittifolium*), taro (*Colocasia esculenta*), and yam (*Dioscorea spp*) to sweet potato (*Ipomoea batatas*), which was previously a minor crop, and this switch may have been at least partially due to Piper, since the yields of the former crops are said to have decreased and it is said that sweet potatoes yield very well after a Piper fallow. *Piper* may have facilitated the development of new human settlements since it makes it easier for people to clear new areas compared with well-developed secondary forests (Ibid.). People also think that *Piper* has rid the area of malicious spirits that used to live in forests.

What is clear from the existing literature is that rural subsistence producers have adapted to IAS generally by incorporating them into their social-ecological systems, even when this requires or permits substantial adjustments to livelihoods, settlement patterns, and production practices. They readily recognise new species and apparently adapt to and manipulate their presence over time, utilising local knowledge that appears to be quickly gained through experience, and adapting or developing local technologies. In the case of *Piper*, which could be characterised as a 'useful aggressive' IAS, it is possible to question whether adaptation has caused these communities to cross a 'threshold' of one or more of the curves presented in the graphs, since (a) it appears that there have been substantial changes in the social-ecological system; (b) there have quite clearly been environmental costs but what these costs are have not yet been investigated; and (c) it is not clear whether the invasion has reached an intermediate phase and *Piper* abundance may continue to increase. Nor is it clear to what degree the exploitation of *Piper* is controlling, or contributing to, its abundance. It is also less clear from all of these reviewed cases how people adapt, or mal-adapt, to species that are of the highly aggressive, low benefit type. The research that has been published so far also tends to reflect contexts in which IAS have invaded over a relatively long timeframe, and where there have been few IAS that people must contend with simultaneously.

The importance of carrying out ecological and socio-economic research in this context cannot be overstated. Perrings (2005) called attention to this when he discussed the needs for careful cost-benefit analysis of IAS control measures:

> to calculate the net benefit of restoration, control or eradication measures requires an evaluation not just of the damage or forgone costs of invasive species and the cost of control, but also of the benefits conferred by the invader or the activities that support the introduction or spread of the invader, and the distribution of the benefits...When those benefits are taken into account it is not always obvious that eradication or control is the optimal strategy (Ibid.).

The literature on IAS emphasises species substitution (using the IAS in place of missing or less accessible native species for particular uses). Other research indicates that people frequently transplant threatened or missing species into homegardens or establish or nurture them in other appropriate micro-environments (e.g. secondary vegetation), although what is successfully transplanted depends on a number of factors including transplanting success (e.g. Niñez 1987, Johnson and Grivetti 2002). Several others demonstrate that people establish what I term 'human biological corridors' to obtain missing seed or species that have become locally extinct, or to which they lose access due to migration or displacement, through extended social networks and/or trade (e.g. Zeven 1999, Greenberg 2003, van Etten and de Bruin 2007). It is widely recognised that most communities continually introduce new species into agricultural fields and homegardens even when native species are not threatened, which is of course one of the sources of IAS, one of the means by which rural dwellers adapt to change and innovate, and one of the sources of species richness in managed environments.

6. Needs for a Research-Policy Programme

The previous sections have argued that biodiversity change that is occurring and that will accelerate over the foreseeable future is unprecedented. Very little is currently known about how humans are adapting to this change and how they are likely to adapt in future. The lack of knowledge, understanding, and conceptual frameworks about autochthonous human adaptation hinders the incorporation of human adaptation to biodiversity change within global, regional, and local environmental change policy, poverty alleviation, and conservation efforts. Most research on human adaptation focuses on climate change without considering effects on biodiversity. Most climate change effects will be felt through their impacts on biodiversity and ecosystem functions and services that are driven by changes in species richness, abundance, and composition. Further, biodiversity change has many other drivers and is an outcome of the interrelation between multiple drivers as well as human responses to such change. Most literature on biodiversity change adaptation focuses on species other than the human species and, when it does focus on humans, adaptations are proposed that tend to be science driven and top-down. Concomitantly, little is known about factors that influence how humans adapt to changes in biodiversity, about how policies affect human adaptation, and how these together might influence human-well being and vulnerability, as well as biodiversity and related ecosystem service outcomes.

A research programme is required to begin to fill this major gap by providing a meta-analysis of extant literature about human adaptation and mal-adaptation to biodiversity change, developing conceptual frameworks and appropriate methodologies, and carrying out multi-disciplinary field research. It is proposed that the research should focus on how people perceive and monitor biodiversity change, means by which they assess such change and make decisions about how to respond both individually and collectively, with special attention to livelihood responses to change in biodiversity assets, and the institutional, economic, cultural and ecological contextual factors and drivers that influence such decisions and their outcomes. In general, the aims of such a programme should be to:

- Understand biodiversity and related ecosystem service response decisions and outcomes in highly biodiversity dependent societies;

- Analyse and document the social, cultural, and ecological drivers and contextual factors that condition these responses;

- Develop models to help forecast adaptive responses and the outcomes with respect to human well-being and biodiversity in different types of social-ecological system and protocols and guidelines to address adaptation to biodiversity change; and

- Embed Human Adaptation to Biodiversity Change as a theme in major national and international research networks and development forums and provide the tools required to achieve this.

References

Abel T, Stepp JR. 2003. A new ecosystems ecology for anthropology. *Conserv Ecol* 7(3): 12.

Altieri MA. 1999. The ecological role of biodiversity in agroecosystems. *Agr Ecosyst Environ* 74: 19-31

Altierri MA. 2000. Multifunctional dimensions of ecologically based agriculture in Latin America. *Int J Sust Dev World* 7: 62-75.

Alvard MS. 2002. Evolutionary theory, conservation, and human environmental impact. In Wilderness and Political Ecology: Aboriginal Influences and the Original State of Nature, ed. C Kay, R Simmons, pp. 28-43. Logan, UT: Utah State Press.

Alvard MS. 2003. The adaptive nature of culture. *Evol Anthropol* 12: 136-49.

Anderies JM, Janssen MA, Ostrom E. 2003. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society 9(1):18.

Atran S, Medin D. 2008. *The native mind and the cultural construction of nature.* Cambridge and London: The MIT Press.

Balée W, Erickson C. 2006. Time, complexity and historical ecology. In *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*, ed. W Balée, C Erickson, pp. 1-17. New York, NY: Columbia University Press.

Battarbee R, Cox P, Freeman C, Lawton J, Mace G, MacKay A, Read D, Shepherd J. 2007. Biodiversity-climate interactions: Adaptation, mitigation and human livelihoods. Report of an international meeting held at the Royal Society, 12-13 June, 2007. London: Royal Society.

Berkes F. 1999. *Sacred Ecology: Traditional Ecological Knowledge and Management Systems.* Philadelphia, PA: Taylor and Francis.

Brush S. 1995. *In situ* conservation of landraces in centers of crop diversity. *Crop Sci* 35(2): 346-54.

Campbell A, Kapos V, Chenery A, Kahn SL, Rashid M, Scharlemann J, Dickson B. 2009. The linkages between biodiversity and climate change adaptation. A review of the recent scientific literature. Oxford: UNEP World Conservation Monitoring Centre.

Chapin FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie S, Mack MC, Diaz S. 2000. Consequences of changing biodiversity. *Nature* 405: 234-42.

Clement D, Shrestha A. 2004. New dimensions in agroecology for developing a biological approach to crop production. *J Crop Improvement* 11(1/2): 1-20.

Cleveland D, Murray S. 1997. The world's crop genetic resources and the rights of indigenous farmers. *Cur Anthropol* 38(4): 477-515.

Commission on Climate Change and Development. Ministry of Foreign Affairs. Government of Sweden. 2009. *The Human Dimension of Climate Adaptation. The Importance of Local and Institutional Issues*, Stockholm.

Conklin H. 1954. *The Relation of Hanunoo Culture to the Plant World.* PhD thesis. New Haven CT: Yale University.

Convention on Biological Diversity (CBD). Secretariat. 2009. Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Montreal. Technical Series No. 41.

Denevan W. 1995. Prehistoric agricultural methods as models for sustainability. *Adv Plant Path* 11:21-43.

Descola P. 1994. *In the Society of Nature: A Native Ecology in Amazonia.* Cambridge: Cambridge University Press.

Didham RK, Tylianakis JM, Gemmell NJ, Rand TA, Ewers RM. 2007. Interactive effects of habitat modification and species invasion on native species decline. *Trends Ecol Evol* 22(9): 489-96.

Dove M, Sajise P, Doolittle A. 2005. *Conserving Nature in Culture: Case Studies from Southeast Asia.* Monograph Series No. 54. New Haven, CT: Yale University Council on Southeast Asia Studies.
Ellen R. 1981. *Environment, Subsistence and System. The Ecology of Small-scale Social Formations.* Cambridge: Cambridge University Press.
Gliessman S. 1998. *Agroecology: Ecological Processes in Sustainable Agriculture.* Ann Arbor, MI: Ann Arbor Press.
GISP. n.d. *Invasive Species and Poverty: Exploring the Links*. Nairobi, Kenya: Global Invasive Species Programme.
Greenberg L. 2003. Women in the garden and kitchen: The role of cuisine in the conservation of traditional house lot crops among Yucatec Mayan immigrants. In *Women and Plants: Gender Relations in Biodiversity Management and Conservation,* ed. P Howard, pp. 51-65. London and New York: Zed Press and Palgrave-Macmillan.
Hannah L, Lovejoy TE, Schneider,SH. 2005. Biodiversity and climate change in context. Pp. 3-14. In *Climate Change and Biodiversity,* ed T Lovejoy, L Hannah, pp. 3-14. New Haven, CT & London: Yale University Press.
Heywood V. 1999. Trends in agricultural biodiversity. In *Perspectives on New Crops and New Uses*, ed. J Janick. Alexandria, VA: ASHS Press.
Howard P. 2008. Draft conceptual framework for understanding human adaptation to biodiversity change. Centre for Biocultural Diversity (CBCD), University of Kent (UK) and Dept. of Social Sciences, Wageningen University (NL).
Howard P, Puri RK, Smith L, Altierri M. 2009. *Scientific conceptual framework and strategic principles for Globally Important Agricultural Heritage Systems.* Rome: FAO.
IPCC-WGII. 2001. Ecosystems and their goods and services. In *IPCC 3rd Assessment Report. Working Group II Report, Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Intergovernmental Panel on Climate Change. Working Group II. Cambridge, UK: Cambridge University Press.
Jarvis D, Padoch C, Cooper C. (eds). 2007. *Managing Biodiversity in Agroecosystems*, Rome and New York: International Plant Genetic Resources Institute (IPGRI) and Columbia University Press.
Johnson N, Grivetti L. 2002. Environmental change in northern Thailand: Impact on wild edible plant availability. *Ecol Food Nutr* 41(5): 373-99.
Kumar B, Nair PKR. 2006. *Tropical Homegardens: a Time-tested Example of Sustainable Agroforestry.* Boca Raton, FL: CRC Press.
Lansing S. 2006. *Perfect Order: Recognizing Complexity in Bali.* Princeton, NJ: Princeton University Press.
Leaky R. 1998. Agroforestry for biodiversity in farming systems. *Biodiversity in Agroecosystems.* ed W Collins, C Qualset. CRC Press: Boca Raton.
Lewis O. 2006. Climate change, species-area curves and the extinction crisis. *Philos Trans R Soc Lond B. Biol Sci* 361:163-71.
Lovejoy T, Hannah L. (eds). 2005. *Climate Change and Biodiversity*. New Haven, CT & London: Yale University Press.
Mace G, Masundire H, Baillie J, Ricketts TH, Brooks T, Hoffmann M, Stuart S, Balmford A, Purvis A, Reyers B, et al. 2005. Biodiversity. In *Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group*, ed R Hassan, R Scholes, N Ash, pp. 77-122. Washington DC: Island Press.
Maffi L ed. 2001. *On Biocultural Diversity: Linking Language, Knowledge, and the Environment.* Washington, DC: Smithsonian Institution Press.
Maffi L. 2005. Linguistic, Cultural, and Biological Diversity. *Annu Rev Anthropol* 29: 599-617.

Malcolm JR, Markham A, Neilson RP, Garaci M. 2005. Migration of vegetation types in a greenhouse world. In *Climate Change and Biodiversity*, ed T Lovejoy, L Hannah, pp. 252-5. New Haven, CT & London: Yale University Press.

Malhi Y, Timmons Roberts J, Betts RA, Killeen TJ, Li W, Nobre CA. 2007. Climate Change, Deforestation, and the Fate of the Amazon. Science 319 (5860): 169-172.

Marten GG. 2001. *Human Ecology: Basic Concepts for Sustainable Development.* London: Earthscan Publications.

McWilliam A. 2000. A plague on your house? Some impacts of *Chromolaena odorata* on Timorese livelihoods. *Hum Ecol* 28(3): 451-69.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. Washington, DC: World Resources Institute.

Moore JL, Manne L, Brooks T, Burgess ND, Davies R, Rahbek C. Williams P, Balmford A. 2002. The distribution of cultural and biological diversity in Africa. *P Roy Soc Lond B.* 269: 1645-53.

Moran EF. 2000. *Human Adaptability: An Introduction to Ecological Anthropology.* 2nd Ed. Boulder, CO: Westview Press.

Niñez VK. 1987. Household gardens: Theoretical and policy considerations. Part I. *Agr Syst* 3: 167-86.

Ostrom E. 2004. Collective action and property rights for sustainable development. Understanding collective action. In *Collective Action and Property Rights for Sustainable Development. 2020 Vision for Food Agriculture and the Environment*, Focus 11, Brief 4, ed R Meinzen-Dick, M di Gregorio, pp. 3-4. Washington, DC: CGIAR System Wide Program on Collective Action and Property Rights (CAPRi) and International Food Policy Research Institute (IFPRI).

Pagel M, Mace R. 2004. The cultural wealth of nations. *Nature* 428: 275-8.

Perrings C. 2005. Biological invasions and poverty. Arizona State University, International Institute for Sustainability. Online at: http://www.public.asu.edu/~cperring

Perrings C, Jackson L, Bawa K, Brussaard L, Brush S, Gavin T, Papa R, Pascual U, de Ruiter P. 2006. Biodiversity in agricultural landscapes: Saving natural capital without losing interest. *Conserv Biol* 20(2): 263-4.

Pimentel D, Lach L, Zuniga R, Morrison D. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50(1): 53-65.

Posey DA. 1985. Indigenous management of tropical forest ecosystems: The case of the Kayapo Indians of the Brazilian Amazon. *Agrofores Syst* 3: 139-58.

Rappaport R. 1984 [1968]. *Pigs for the Ancestors: Ritual in the Ecology of a New Guinea People.* Enlarged ed. New Haven, CT: Yale University Press.

Richerson PJ, Boyd R. 2005. *Not by Genes Alone: How Culture Transformed Human Evolution.* Chicago: University of Chicago Press.

Rockström, J, Steffen, W, Noone, K, Persson, A, Chapin, FSF, Lambin, EF, Lenton, TM, Scheffer, M, Folke, C., Snellnhumber, HJ, Nykvist, B, de Wit, CA, Hughes, T, van der Leeuw, S, Rodhe, H, Sörlin, S, Synder, PK, Constanza, R, Svedin, U, Falkenmark, M, Karlberg, L, Corell, RW, Fabry, VJ, Hansen, J, Walker, B, Liverman, D, Richardson, K, Crutzen, P, Foley, JA. 2009. Planteary boundaries: exploring the safe operating space for humanity. *Ecol Soc*, in press.

Root TL, Hughes L. 2005. Changes in phenology and ecological interactions. In *Climate Change and Biodiversity* ed TE Lovejoy, L Hannah, pp. 61-9, Yale University Press: New Haven.

Salick J, Byg A. Posey D. 2007. *Indigenous people and climate change. Report of Symposium 12-13 April 2007. Environmental Change Institute, Oxford.* Online at: http://www.tyndall.ac.uk/publications/Indigenouspeoples.pdf.

Sastrapradja SD, Balakrishna P. 2002. The deployment and management of genetic diversity in agroecosystems. In *Managing Plant Genetic Diversity*, ed JM Engels, V Ra-

manatha Rao, AH Brown, MT, Jackson, pp. 121-32. Rome: International Plant Genetic Resources Institute.
Sax DF, Stachowicz JJ, Brown JH, Bruno JF, Dawson MN, Gaines SD, Grosberg RK, Hastings A, Holt RD, Mayfield MM, O'Connor MI, Rice WR. 2007. Ecological and evolutionary insights from species invasions. *Trends Ecol Evol* 22(9): 465-71.
Scoones I. 1999. New ecology and the social sciences: what prospects for a fruitful engagement? *Ann Rev Anth* 28: 479-507.
Shackleton CM, McGarry D, Fourie S, Gambiza J, Shackleton SE, Fabricius C. 2007. Assessing the effects of invasive alien species on rural livelihoods: Case examples and a framework from South Africa. *Hum Ecol* 35: 113-27.
Siges TH, Hartemink AE, Hebinck P, Allen BJ. 2005. The invasive shrub *Piper aduncum* and rural livelihoods in the Finschhafen area of Papua New Guinea. *Hum Ecol* 33(6): 875-93.
Smith EA. 2001. On the coevolution of cultural, linguistic, and biocultural diversity. In *On Biocultural Diversity*, ed L Maffi, pp. 95-117. Washington, DC: Smithsonian Institution Press.
Sutton MQ, Anderson EA. 2004. *Introduction to Cultural Ecology.* Oxford: Berg.
Thomas CD, Cameron A. Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BF, de Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Townsend Peterson A, Phillips OL, Williams SE. 2004. Extinction risk from climate change. *Nature* 427: 145-8.
Van Etten J, de Bruin S. 2007. Regional and local maize seed exchange and replacement in the western highlands of Guatemala. *Plant Genetic Resources* 5: 57-70.
Van Vuuren D, Sala, OE, Pereira, HM. 2006. The future of vascular plant diversity under four global scenarios. *Ecol Soc* 11: 25.
Vandermeer JH, ed. 2002. *Tropical Agroecosystems.* Boca Raton, FL: CRC Press.
Verchot LV, Noordwijk M, Kandji S, Tomich T, Ong C, Albrecht A, Mackensen J, Bantilan C, Anupama KV, Palm C. 2007. Climate change: linking adaptation and mitigation through agroforestry. *Mitig Adapt Strat Glob Change* 12(5): 901-918.
Williams JW, Jackson ST, Kutzbach JE. 2007. Projected distributions of novel and disappearing climates by 2100 A.D. *P Natl Acad Sci* 104(14): 5738-42.
World Wildlife Fund (WWF). 2006. Climate change impacts in the Amazon: Review of scientific literature. Washington DC: World Wildlife Fund.
Zeven AC. 1999. The traditional inexplicable replacement of seed and seed ware of landraces and cultivars: A review. *Euphytica* 110: 181-91.
Zimmerer K. 1996. *Changing Fortunes: Biodiversity and Peasant Livelihood in the Peruvian Andes.* Berkeley, CA: University of California Press.