Loss and Damage: The Role of Ecosystem Services

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Table of Contents

List of figures

Acronyms and Abbreviations

ALP	Adaptation Learning Programme
AR5	Fifth Assessment Report
BRAC	Bangladesh Rural Advancement Committee
CBA	Community Based Adaptation
CIESIN	Center for International Earth Science Information Network
CLICC	Country-Level Impacts of Climate Change
CVM	Contingency Valuation Method
DRR	Disaster Risk Reduction
EEA	European Environment Agency
FbF	Forecast-based finance
FONDEN	Fund for Natural Disasters
GEF	Global Environment Facility
GFDRR	Global Framework for Disaster Risk Reduction
GLOF	Glacial Lake Outburst Flood
IFRC	International Federation of the Red Cross
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NELD	Non-Economic Loss and Damage
NOAA	National Oceanic and Atmospheric Administration
OCHA	Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goals
SGP	Small Grants Programme
SOPs	Standard Operating Procedures
TEEB	The Economics of Ecosystems and Biodiversity
UNCCD	United Nations Convention to Combat Desertification
UNITAR	United Nations Institute for Training and Research
UNFCCC	United Nations Framework Convention on Climate Change
UNOSAT	UNITAR - Operational Satellite Applications Programme
USGS	United States Geological Survey
WIM	Warsaw International Mechanism

Summary

Loss and damage refers to the adverse effects of climate-related stressors on natural and human systems that cannot be, or have not been, avoided through mitigation or managed through adaptation efforts. Climate change is increasing the risk of loss and damage from extreme weather and slow onset events. Loss and damage has become a major policy issue as identified in the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement's Article 8 states: "Parties recognize the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage." Work had begun in 2013 when the Warsaw International Mechanism (WIM) for Loss and Damage associated with climate change impacts was established under the UNFCCC. Functions of WIM include enhancing knowledge to address loss and damage, strengthening dialogue among stakeholders, and enhancing action and support.

To date, studies of loss and damage have focused primarily on human systems and tended to overlook the mediating role of ecosystems and the services ecosystems provide to society. This results in a serious knowledge gap. Climate-induced loss and damage to human systems may result from permanent or temporary effects of climatic stressors on ecosystems and the services they provide. More information is needed. Indeed, the Paris Agreement urges Parties to enhance understanding, action and support in areas such as, "Resilience of communities, livelihoods and ecosystems".

Therefore this report tries to advance understanding of climatic stressor effects on ecosystems and possible correlations and implications for societal losses and damages. Five case studies from Asia, Africa, Europe, and North America are used to illustrate effects through real-world examples, covering a range of climatic stressors, such as drought, floods, heat waves, and cyclones. Several of the case studies describe extreme events which appear to have been made more likely due to climate change, and events of this nature may be more likely as climate change intensifies.

A variety of ecosystems services have been affected, both positively and negatively, including provisioning services of food production and water supply, regulating services supporting flood prevention and health, and supporting services related to primary productivity. In South Asia, extreme heat events coupled with extreme rainfall resulted in threats to human health and loss of property and lives. Floods have also caused severe erosion and landslides in mountain areas. Ecosystem services are literally being eroded as intense rainfall and increased glacial runoff combine to worsen flood events. In the Sahel region, temperature increase, rainfall variability, and decreases in rainfall in some areas have led to crop losses and the decline of one of the world's largest inland lakes, Lake Chad.

The case studies show that causal links between climate change and a specific event, with subsequent loss and damage, are often complicated. Oversimplification must be avoided and the role of different factors, such as governance or management of natural resources, should be explored further. For example, lack of investment in water related infrastructure, improved agricultural technology, or health care services also influences the risk of loss and damage. In the South Asia case study, deforestation and increases in paved surfaces have influenced flooding as much as extreme rainfall. In the Sahel, variability in rainfall patterns influences primary productivity, but barriers to pastoralists' freedom of movement have also increased their vulnerability to droughts. During the 2003 heat waves in France, health hazards developed from an intricate association of both natural and social factors.

The cases also show that while some adaptation measures have been implemented, loss and damage has nevertheless occurred. For instance, adaptation measures in both East and West Africa include crop-livestock integration, soil fertility management, planting of drought-resistant crops, water harvesting, dug ponds for watering animals, livelihood diversification, and seasonal or permanent migration. A number of these methods have been practiced for generations. However, as changing climate intensifies, promising practices will have to scale up and new methods devised.

A win-win solution will be to invest in ambitious mitigation action to avoid the unmanageable, and comprehensive and holistic adaptation action to manage the unavoidable–including better management of ecosystems and their services, improved governance, and economic policies that support sustainable development. For example, the San Joaquin Valley, California, case study concludes that the prudent policy is the deliberate democratic management of water. This will require creating a broad-based consensus on water

use, strategic investing in education and technology, and follow through the State's 2012 Human Rights to Water Bill. Governments must accelerate progress towards adaptation goals as well as towards aspirations of the Sendai Framework for Disaster Risk Reduction 2015-2030 and Sustainable Development Goals.

Ultimately, a range of approaches is needed to address climate change impacts to ensure that resilience building efforts and sustainable development can continue. Chapter 4 of this report provides a specific set of policy options to avert loss and damage, and to address loss and damage that have not been or cannot be averted through enhanced mitigation and adaptation. These options include risk transfer, which can be used to both avoid and address loss and damage; risk retention, such as social protection policies; migration, recovery, rehabilitation and rebuilding in the wake of extreme events; and tools to address non-economic loss and damage. This report finds that approaches to avert and limit loss and damage as well as to address the residual impacts of climate change will be more successful if they incorporate inclusive decision making, account for the needs of a wide range of actors, and target the poor and vulnerable.

As loss and damage is a new and emerging topic in science and policy, there are more unanswered questions than answers at present. This report identifies important areas for future research and evidence gathering that include:

- Increasing understanding of how loss and damage to human well-being is mediated through loss and damage to ecosystem services and of the specific policy entry points. This includes more study of the adverse impacts of climate change, including climate extremes, on ecosystem function. Examples may include the effects of extreme heat and drought on forest ecosystems, the consequences of sea level rise and storm surge for coastal ecosystems ranging from sea grasses and marshes to mangroves, and the implications of glacier loss on downstream hydrology and riparian ecosystem function;
- Documenting and evaluating the effect of efforts to avert loss and damage and identifying how the efficacy of tools and measures can be improved, including how non-economic loss and damage associated with the loss of ecosystem services

Damage to ecosystem due to a landslide, Nepal, 2014

Photo credit: Kees van der Geest

can be better addressed. This includes gathering evidence on the potential for, and the limits to, ecosystem-based adaptation in a number of areas. Examples may include the ability of intact mangrove ecosystems to limit coastal erosion from sea level rise and storm surge, the potential for wetlands to mitigate flood damage by absorbing runoff from heavy rainfall and releasing water gradually, or the potential and the limits for greening urban areas to reduce heat stress and consequent remediation of health risks;

- Developing a best practice suite of policies, programs, and tools, to help governments and communities identify ways to avert loss and damage;
- Clarifying the ambiguity between avoidable and unavoidable loss and damage, as well as with the concept of "averting" loss and damage used in the 2015 Paris Agreement. This includes identifying where the limits of adaptation lie and how loss and damage is incurred when those limits are reached. Some extreme weather events and climatic processes will be too great in magnitude and extent for adaptation. In that sense, they are beyond adaptation. The case studies show the adaptation limits in regards to temperature extremes are already being met in certain areas. Temperature increases may be beyond the limit of crops during critical points in their life cycle, resulting in failed food production. Novel approaches are needed to address any unavoidable loss and damage.

1. Introduction

Climate change is already increasing the risk of some extreme weather events such as heat waves and heavy rainfall, with implications for loss and damage affecting vulnerable populations around the world. According to the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), global surface temperatures have warmed on average 0.85° C relative to pre-industrial temperatures (IPCC, 2014). Moreover, a recent report commissioned by the World Bank found increasing evidence that even with very ambitious mitigation measures, the Earth's atmospheric system may already be committed to warming of approximately 1.5° C above pre-industrial levels by 2050 (World Bank, 2014). While mitigation continues to be of paramount importance to limit loss and damage, the extent and magnitude of climate change impacts will certainly increase in the future. Decision makers will need to be prepared to implement both adaptation and risk reduction measures to avoid loss and damage and a suite of other approaches within comprehensive risk management frameworks to address loss and damage that is not averted.

1.1 Policy Background

Loss and damage has emerged in the past decade as a key issue under the United Nations Framework Convention on Climate Change (UNFCCC) and is an area of increasing concern for national policy makers (Roberts and Huq, 2013). Although the concept was already introduced during the negotiations that culminated in the establishment of the Convention in the early 1990s, loss and damage first appeared in a UNFCCC document in the Bali Action Plan in the context of developing a means to address loss and damage through enhanced adaptation action (Roberts and Huq, 2015; Warner and Zakieldeen, 2012). A work programme to better understand loss and damage was established under the Cancun Adaptation Framework at COP 16 in 2010 (UNFCCC, 2011), as a result of recognition that more effort was needed to improve understanding while also improving coordination of action and mobilizing support for developing countries (Roberts and Huq, 2015). Two years later during negotiations in Doha it was decided that a formal institutional arrangement would be established to address loss and damage (UNFCCC,

Flood in the Upper Mekong Delta, Vietnam, 2011.

Photo credit: Kees van der Geest

Arial view of flood in the Upper Mekong Delta, Vietnam, 2011.

Photo credit: Kees van der Geest

2013). In 2013, the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts (WIM) was established under the Cancun Adaptation Framework (UNFCCC, 2014; Stabinski and Hoffmaister, 2015). In 2015, in Paris parties decided that the Warsaw International Mechanism will continue to exist as the body to address loss and damage past 2016 when it will undergo a review. However, the agreement established loss and damage as distinct from adaptation and sets the stage for further work to address loss and damage, both within and outside the UNFCCC. The Agreement outlines several possible areas for cooperation and facilitation to enhance understanding, action, and support including on early warning systems; emergency preparedness; slow onset events; irreversible and permanent loss and damage; comprehensive risk assessment and management; risk transfer; non-economic losses; and the resilience of communities, livelihoods, and ecosystems.

1.2 What is loss and damage?

No universally agreed-upon definition of loss and damage exists, and a fit-for-purpose working definition varies by scale and purpose (see Box 1.2.1). This report refers to loss and damage as the adverse effects of climate-related stressors that cannot be or have not been avoided through mitigation or managed through adaptation efforts (adapted from Van der Geest and Warner, 2015). Loss and damage can become evident when adaptation measures are unsuccessful, insufficient, not implemented, or impossible to implement; or when adaption measures incur unrecoverable costs or turn out to be measures that increase vulnerabilities, called maladaptation (Warner and van der Geest, 2013).

Verheyen (2012) introduced a policy-relevant distinction between avoided, unavoided, and unavoidable loss and damage. Avoided loss and damage is a hypothetical category of impacts that have been prevented through mitigation and adaptation measures. For example, if an African dryland farmer has planted drought-resistant crop varieties that yielded well in a season of extremely low rainfall, he or she has avoided loss and damage. Unavoided loss and damage refers to impacts of climate change that can in theory be avoided but that have not been avoided because mitigation and adaptation efforts were insufficient. For example, “unavoided loss and damage” may result if a coastal storm and high waves inundate and destroy properties because available measures to adapt to rising sea levels were not implemented. By contrast, impacts that are impossible

Box 1.2.1 Defining loss and damage:

A fit-for-purpose definition of loss and damage in the global arena differs from a workable definition for empirical research at the local level. At the international level, loss and damage can be understood as the impacts of climate change that are not avoided by mitigation and adaptation efforts (Roberts and Huq, 2015; Parker et al., 2016) while at the local level loss and damage can be understood as those impacts of climate-related stressors that are not avoided by coping and adaptation (Warner and van der Geest, 2013). The definitions differ in (1) the attention for mitigation efforts (less relevant in local case studies); 2) the ability to attribute climatic stressors to anthropogenic global warming (also less relevant in local case studies); and 3) the need to assess the effectiveness of people's measures to cope with adverse events (relevant for local case studies). For some observers 'coping' has a negative connotation because it refers to short-term solutions for immediate stressors that are not always sustainable in the longer term. However, just like in the case of adaptation and maladaptation, a distinction can be made between coping and 'erosive coping'. The latter involves measures that undermine future livelihood sustainability (van der Geest and Dietz, 2004).

to avoid through mitigation and adaptation efforts are characterized as "unavoidable loss and damage" (Verheyen, 2012). In reality there is ambiguity around what can and what cannot be avoided, depending on whether this is determined by technological, social, economic or political limits to mitigation and adaptation. Strong disaster mitigation, for example, might be technically possible but not politically feasible. Similarly, if a small, low-lying atoll would be confronted with six meters of sea level rise, it could be technically possible to build a large dyke around it, but most likely the costs of such an effort would be prohibitive. This report does not attempt to resolve these ambiguities. However, it is important to acknowledge that they exist because there are important policy implications. In some cases, resources would be invested most efficiently in attempts to avert loss and damage and in other cases, it will be better to accept losses and find dignified solutions for the people who are affected by these losses.

A useful concept in the discussion about avoidable and unavoidable loss and damage is 'adaptation limits' (Dow *et al.,* 2013; Preston *et al.,* 2013; Warner *et al.,* 2013). The IPCC describes the limits to adaptation as having been reached when adaptation is no longer able to "provide an acceptable level of security from risks to the existing objectives and values and prevent the loss of the key attributes, components or services of ecosystems" (Klein *et al.,* 2014). Hard adaptation limits occur when no adaptive actions are possible to avoid intolerable risk, while soft adaptation limits occur when options are currently not available to avoid intolerable risk through adaptive action (Agard *et al.*, 2014). In practice, it is not always clear whether an adaptation limit is hard or soft. Dow and others (2013) maintain that once actors reach an adaptation limit they have two choices: incur loss and damage or transform.

A body of fieldwork-based evidence is emerging which shows that vulnerable populations in developing countries are already reaching adaptation limits. In 2012-2013 United Nations University undertook case studies in nine developing countries to better understand how loss and damage is being experienced at the household level (Warner and van der Geest, 2013). The study in northern Burkina Faso, for example, found that 93 percent of those surveyed had experienced threatened livelihoods following a 2010 drought (Traore and Owiyo, 2013). Many experienced crop failure, the effect of which was worsened by spiking food prices. Almost all households implemented coping strategies—such as selling livestock to buy food, modifying food consumption, or migration—but for 71 percent these measures were insufficient. In the Satkhira District of coastal Bangladesh, the loss and damage case study looked at the double threat of sea-level rise and cyclones (Rabbani *et al.,* 2013). Both threats result in saltwater intrusions that alter coastal ecosystems and reduce their provisioning services. The salinity of river water, soils, and groundwater in the region has increased sharply over the past two decades, with stark implications for rice cultivation, which is the mainstay of the local economy. To adapt to higher salinity in soils, farmers planted new salt-tolerant rice varieties. This strategy worked reasonably well until 2009, when cyclone Aila hit the area and delivered a sudden and drastic increase of salt content to the soil. Almost all farmers in the area lost their complete harvest that year and their soils could not be cultivated for several years. The findings from the Bangladesh study demonstrate seemingly successful measures to adapt to slow-onset processes prove insufficient when the situation is aggravated by an extreme weather event. When current adaptation limits are breached, loss and damage result.

Jointly, the case studies identified four different patterns or pathways in which households incur loss and damage. This is the case when:

- measures to cope or adapt were not enough
- measures had costs that were not recovered
- measures had erosive effects in the longer term
- No measures were adopted at all (Warner and Van der Geest, 2013).

Woman carrying pots on a dry river bed in Boubon, Niger.

Photo credit: Fernando Sánchez Bueno

In all nine studies the repercussions on human well-being followed the loss of ecosystem services.

A common way of analyzing loss and damage is by differentiating between economic and non-economic loss and damage (NELD). Economic losses are understood to be the loss of resources, goods and services that are commonly traded in markets, such as livestock and cash crops. Non-economic losses involve those "items" that are not commonly traded in markets (UNFCCC, 2013). Examples of NELD in natural systems include loss of habitat and biodiversity and damage to ecosystem services. While not traded in markets as such, there is extensive experience and expertise in valuing the services ecosystems provide (Costanza *et al.*, 2014). Examples of NELD in human systems include cultural and social losses associated with the loss of ancestral land and forced relocation. Such climate change impacts are difficult to quantify but important to address (Morrissey and Oliver-Smith, 2013).

Loss and damage can also be categorized as direct and indirect. Examples of direct types include loss of life, land, crops, or livestock–as well as damage to houses, properties, and infrastructure. Such outcomes are generally quite well covered in disaster loss assessments (Gall, 2015). By contrast, indirect losses and damages are harder to quantify or estimate, so they are often underreported (UNFCCC, 2012). Indirect losses and damages are associated with the direct types and with the measures adopted to cope. For example, if a community is displaced by flooding and has to live in a school building for six months, there will be indirect effects of the flood on the students' education level (Opondo, 2013).

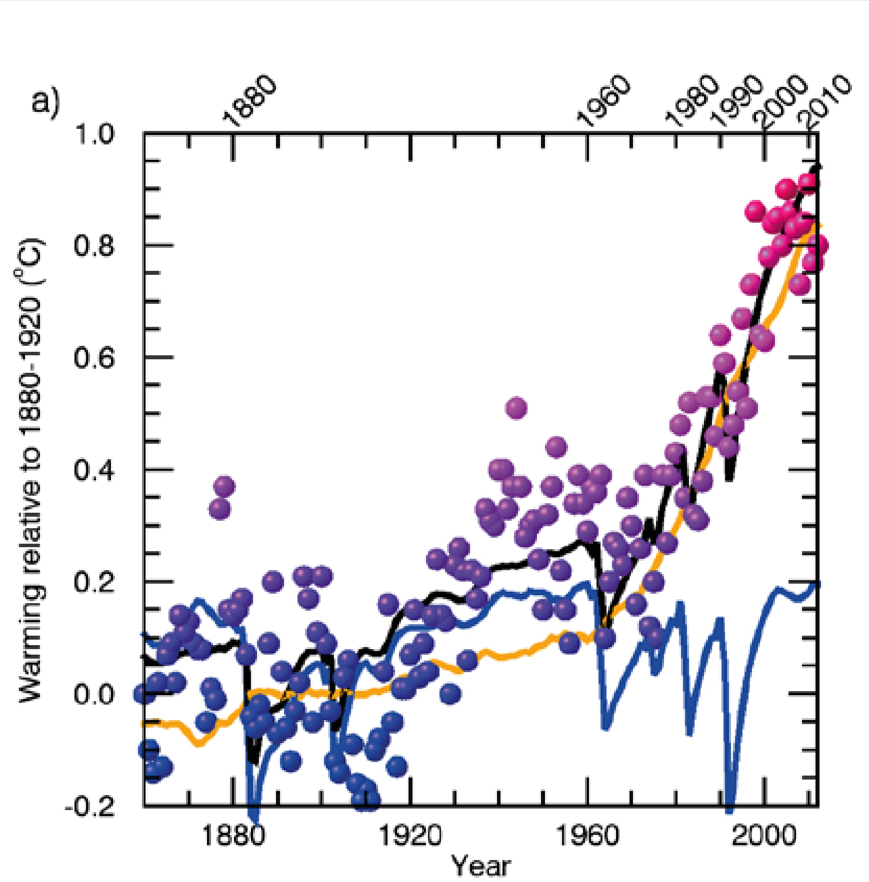
1.3 Attribution to climate change

The emerging loss and damage agenda has raised questions about whether the impacts of specific weather events are attributable to anthropogenic climate change. Attribution involves identifying a causal chain from emissions to impacts (Hansen *et al.,* 2015). To say that loss and damage is due to human-induced climate change, an extreme weather event or slow-onset process would need to be linked to global warming, and the loss and damage itself would need to be linked to the climatic event (See Box 1.3.1). This is by no means an easy task as there are many other drivers of risk, including land use change, inherent vulnerabilities, governance,

Box 1.3.1 Attributing climate-related events to anthropogenic emissions

Scientists can make very confident statements about the influence of human activity on long-term changes in global climate. The latest IPCC report states that warming of the climate system is unequivocal, and that it is extremely unlikely that the observed increase in global temperatures would have occurred without anthropogenic greenhouse gas emissions (IPCC, 2014). These statements are based on 'detection and attribution' analysis. Observed trends in climate are compared to model simulations with and without certain drivers–including carbon dioxide, methane, anthropogenic aerosols, solar variability, and volcanic eruptions–to test the relative importance of each forcing factor (Figure 1.3.1).

Figure 1.3.1 Example of a simplified detection and attribution study.



In the figure, points show global temperature anomalies relative to 1880-1920. These are compared to model simulated temperatures with natural forcings only (blue), anthropogenic forcing only (orange), and a combination of natural and anthropogenic forcings (black). As shown, the observations can only be reproduced with both natural and anthropogenic forcing. *Source: IPCC AR5 WGI, Box 10.1 Figure 1, p.876.*

As well as demonstrating an anthropogenic signal in global warming, these scientific studies also show that humans are influencing trends in other variables, including regional temperatures and global sea levels (IPCC, 2014). Trend attribution studies might therefore provide relevant evidence about the influence of anthropogenic climate change on slow onset events.

For extreme weather events, attribution is more difficult. There is evidence that climate change causes some extreme events to occur more often, or to become more intense (IPCC, 2012), but it is difficult to link specific extreme events to climate change. Due to natural variability, it is impossible to say that any specific heat wave, flood, or drought would not have occurred without human influence on climate. However, it is not impossible to say anything at all. We can investigate whether human activity has altered the probability of an event (Allen, 2003). To use an analogy of a loaded dice: if a six is rolled, it is not possible to say that the six would not have occurred without the loading; nonetheless, we can say that the loading increased the probability of the six. Probabilistic attribution of extreme events might therefore contribute to an assessment of whether human emissions increased the risk of loss and damage from specific extreme events. It may equally demonstrate that anthropogenic activity has decreased the risk of some events (Kay *et al.*, 2011).

There are many uncertainties associated with attribution results, as well as disparity in the evidence base (James et al., 2014). There is currently much more evidence available for developed than for developing countries (Pall *et al.*, 2011; Otto *et al.*, 2012). Scientists have more confidence in research about some extreme events than others: they can make stronger statements about heatwaves than precipitation-related events, and it is difficult to make attribution statements about hurricanes and typhoons. Modelling is difficult for some events with unusual atmospheric circulation systems: it is sometimes not possible to draw conclusions, as was the case for the 2010 floods in Pakistan (Christidis *et al.*, 2011). The science is advancing rapidly however. The first study attributing an extreme event to climate change was published in 2004 (Stott *et al.*, 2004) and now there are many events being investigated each year: 32 attribution studies were recently published that focus on events of 2014 (Herring *et al.*, 2015). For a detailed review of the state of science see National Academics of Sciences, Engineering, and Medicine (2016).

In cases where formal detection and attribution studies have not yet been undertaken, or their results are inconclusive, the evidence about the role of climate change is less robust, but it may still be possible to make useful inferences and projections based on past trends and physical understanding (Huggel *et al*., 2015)

and the degree of preparation. However, the science of attribution is advancing rapidly (Herring *et al.,* 2015) as well as our understanding of how people experience loss and damage from climate-related events (Warner and Van der Geest, 2013). Attribution science could play a key role in improving understanding of how climate change influences risk. This improved understanding could be essential information for decision makers challenged by climate-induced loss and damage now, and into the continually changing climate of the future (James *et al.*, 2014).

While advancing attribution science is a worthy pursuit, addressing loss and damage cannot be dependent on its progress. Indeed, if the aim is to minimize future loss and damage and to help vulnerable people overcome the loss and damage that cannot be averted, there are many actions that can be taken to address vulnerability and risk without an exact calculation of the contribution from climate change.

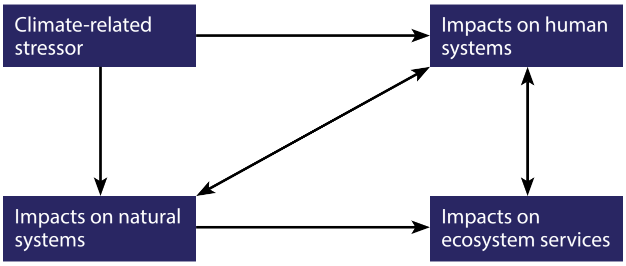
To address the threat of loss and damage we should consider the climate change signal, but not limit ourselves to cases that are attributable to climate change. In the case studies presented in this report, we discuss loss and damage from a range of climate-related stressors, and we will present the current evidence about the climate change signal in each of these.

1.4 Knowledge gap

There is a long tradition of work on assessing disaster losses, and a more recent, but still small, body of literature on loss and damage from climate change. There is more experience and literature available with respect to sudden onset impacts than slow onset impacts like sea level rise and ocean acidification. While scientific conceptualizations of loss and damage have focused on human impacts (Warner and van der Geest 2013; Wrathall *et al.*, 2014), little attention has been given to the loss of ecosystem services and the cascading impacts on human societies resulting from this (Zommers *et al.*, 2014). Yet, according to the IPCC's AR5, "evidence of climate-change impacts is strongest and most comprehensive for natural systems" (IPCC, 2014). Moreover, adaptation options for ecosystems are limited (IPCC, 2014) and in the case of progressive and permanent change, current measures are unlikely to prevent loss and damage to ecosystems and their services.

Figure 1.4.1 shows two ways in which climate-related stressors affect human beings. Climate-related stressors are events or trends that have an important effect on the system exposed and can increase vulnerability to climate-related risk (Agard *et al.*, 2014). Climate-related stressors can cause loss and damage to human systems directly, such as when a cyclone tears off a roof, or indirectly through changes in ecosystem services, such as when a drought reduces water availability for agriculture.

Figure 1.4.1 Relationship among climate change, ecosystem services, and human systems.



Climate change can affect human systems directly, but damages to natural systems and ecosystem services also threaten society.

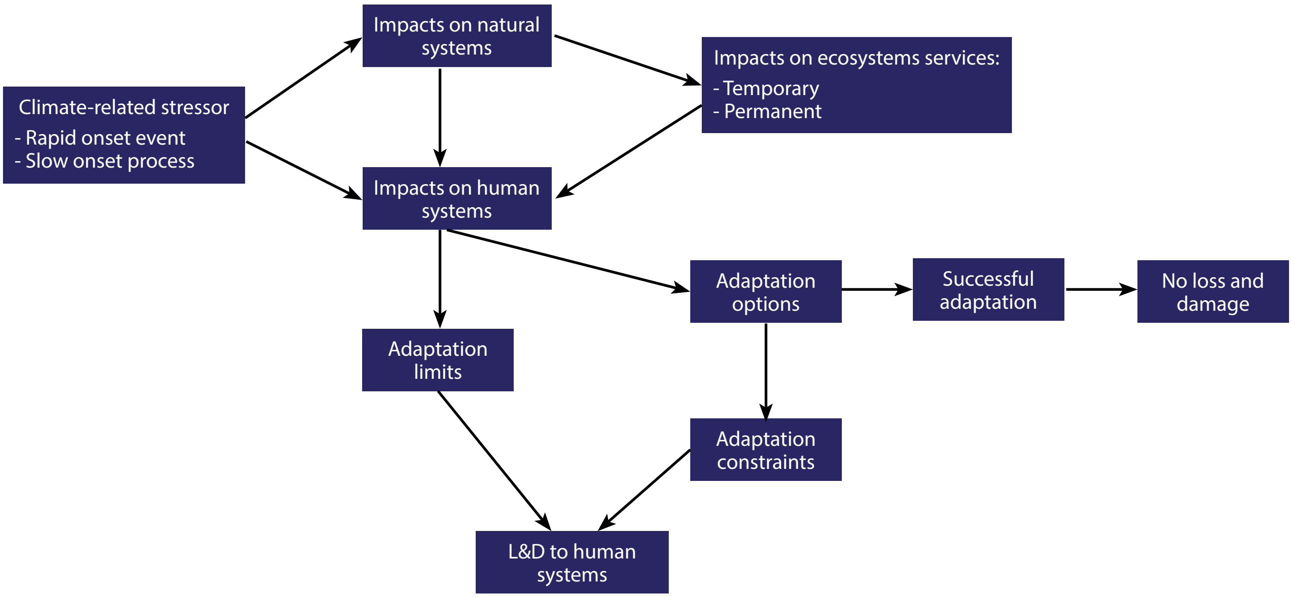
Note: separating human and natural systems in this diagram is a heuristic device that aims to illustrate the two ways in which climatic stressors can cause loss and damage that require different approaches in analysis and policy. In reality, however, human and natural systems interact continuously and are shaped by each other.

Zommers *et al.* (2014) compile research that documents how climate change can degrade ecosystems and the services they provide with consequences for human society. Increasing temperatures in the Peruvian Andes lead to glacial retreat that disrupts river flows. River discharge increases when melt is highest and then dissipates over years as glaciers lose volume. Glacier loss has profound effects on the ecosystem's provisioning services that support human livelihoods, such as flood control and water supplies for agriculture. Floods can take lives, damage livelihoods, and result in a myriad of non-economic losses and damages on health, education, and overall well-being. Periods of low water threaten crop production with repercussions that also cascade through societal systems and affect food security, health, market prices, and population movements.

1.5 Conceptual framework

Our working definition refers to loss and damage as the adverse effects of climate-related stressors that cannot be or have not been avoided through mitigation or managed through adaptation efforts. In line with this definition, Figure 1.5.1 illustrates that there is a conceptual difference between climate impacts and loss and damage. Loss and damage refers to adverse consequences, despite or beyond mitigation and adaptation efforts. Too many opportunities to mitigate or adapt are missed because of lack in understanding, deficits in long-term commitment and motivation, and inadequate financial resources. Loss and damage can result from these failures.

Figure 1.5.1 Conceptual framework for this report



The purpose of this framework is to illustrate the central focus and storyline in this report. It does not elaborate on all elements and relations of the complex reality of climate change, impacts, and adaptation. Therefore, the diagram has several 'missing arrows'. For example, readers could have expected an arrow from adaptation back to natural systems. Climate change adaptation can degrade the environment further, for example when people migrate and deforest a new area or when a sea wall disrupts mangroves along the shore. Another missing arrow could be from the impacts on ecosystem services box back to the stressor box. An example is when mangroves loss leads to more severe storm surges (Monnereau and Abraham, 2013). Such feedbacks are not included in the diagram because they are not the central focus of this paper, but could be explored in future research.

Starting at the top of the diagram, climatic stressors affect human systems, natural systems, and ecosystem services. As explained in section 1.4, effects on human systems can be direct, or indirect through damage to natural systems or ecosystem services. When human systems are affected directly or indirectly, adaptation options may exist. If there are no adaptation options at all, when adaptation limits have been surpassed, then there will be loss and damage to human systems. If there are possibilities to adapt, the efficiency of adaptation actions will determine whether loss and damage is successfully averted. Often, successful adaptation is possible in theory, but doesn't happen in practice because of adaptation constraints, such as lack of knowledge, skills, and resources.

1.6 Purpose and outline of the report

This report aims to enhance our understanding of how and when climate change threats to ecosystem services result in loss and damage to human societies. This will serve as a starting point for assessing what kind of interventions could reduce such losses and damages now and in the future. Chapter 2 looks at climate change impacts on ecosystem services. It discusses four different types of services—provision, regulating, supporting, and cultural—and presents some examples of how these are affected by climate change. Chapter 3 highlights some case studies from around the world. The cases illustrate how loss and damage to ecosystem services from both extreme weather events and slow onset climatic processes affect human well-being. Chapter 4 discusses the policies and strategies that can be implemented to avert loss and damage, and to deal with the repercussions of those that cannot be averted.

2. Impacts of climate change on ecosystem services

Ecosystems are the collections of macro and microscopic biota that form critical life support systems. Globally and locally overexploitation is degrading ecosystems. The services that ecosystems provide are undervalued and under-recognized by current resource management approaches, yet are critical to human well-being (WWAP, 2015; MA, 2005). Climate change has the potential to exacerbate ecosystem degradation and reduce the efficiency of ecosystem services (Staudinger *et al.,* 2012; Bangash *et al.,* 2013; and Lorencová *et al.*, 2013).

Fisherman along the Jamuna River (Brahmaputra River) in Bangladesh which is affected by river bank erosion. Food from fisheries is an example of a provisioning service provided by the environment.

Photo credit: Stefan Kienberger

Many of the negative consequences human societies stand to experience from climate change are tied to the adaptation limits of individual species upon which we depend for food, fiber, fuel and shelter, as well as the services provided by whole ecosystems. Dow and others (2013) provide examples of limits to adaptation. Temperature constraints on rice pollination and flowering in South Asia provides their first example: After a threshold temperature of 26° C, every 1° C increase in night-time temperature results in 10percent decline in yield. Beyond a night temperature of 35° C it is impossible to grow current rice varieties there, which constitutes an adaptation limit beyond which different types actors (farmers, traders, the economy at large) can incur losses and damages due to changes in the ecosystem service (Dow *et al.,* 2013).

The second example demonstrates how a society itself can choose its adaptation limits: After settling in Greenland around 1000AD, the complex and vibrant Norse society there ended around 1450. The settlements' collapse can be attributed to their adaptation limits. When harsh conditions began, Norse Greenlanders adopted new ways of exploiting marine mammals as declines in agriculture and domestic livestock production persisted. But faced with growing competition from Inuit hunters, declining trade in ivory and fur with Norway as pack ice blocked their access, and a generally chilling climate,

these adaptations were insufficient to maintain risks to community continuity at tolerable levels. At the same time, they refused to adopt techniques that proved useful to the Inuit (Dow *et al.*, 2013).

This chapter highlights the results of some recent studies which evaluate climate change impacts on ecosystem services. It is clear that impacts of climate change on ecosystem services are characterised by high levels of complexity arising from interactions of biophysical, economic, political, and social factors at various scales (Ewert *et al.,* 2014). These impacts are often specific to a given context or place, and may produce positive or negative outcomes, making generalizations difficult.

2.1 Example of climate change impacts on provisioning services

2.1.1 Water

A decline in the quantity and quality of water is expected in the face of increasing climate change (Reddy *et al.,* 2015). The IPCC's AR5 projects that over the 21st century climate change will reduce renewable surface water and groundwater quantity significantly in most dry subtropical regions. Combined with changes in rainfall patterns, pollutants, sediments, and nutrients loadings, higher temperatures will also reduce the quality of drinking water (IPCC, 2014, Bangash *et al.*, 2013). At the same time, the demand for both river water and

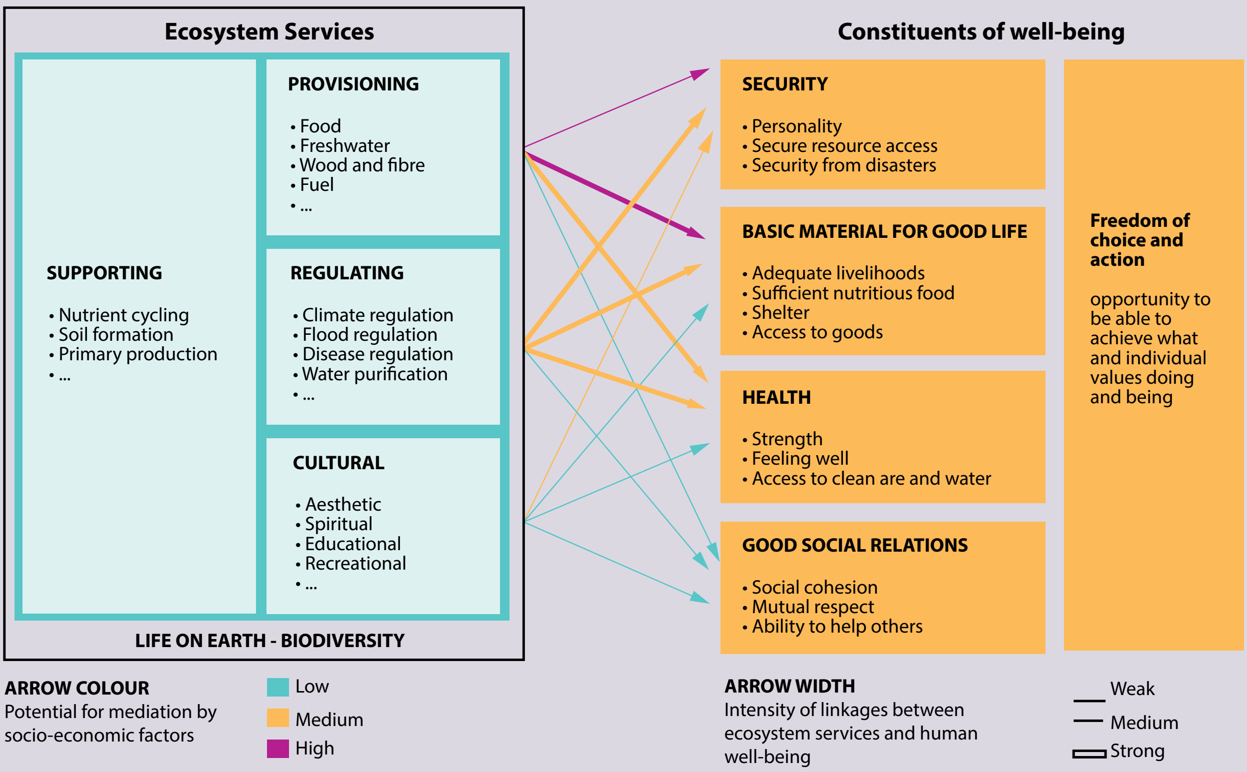
Box 2.1.1 Defining Ecosystem Services

The Millennium Ecosystem Assessment simply defines ecosystem services as the benefits that people obtain from ecosystems (MA, 2005). There are four types of ecosystem services:

- provisioning services (food, water, fuel and wood or fiber)
- regulating services (climate, flood and disease regulation and water purification)
- supporting services (soil formation, nutrient cycling and primary production)
- cultural services (educational, recreational, aesthetic and spiritual).

In general, service delivery increases with the level of intactness, complexity, and/or species richness of ecosystems (Díaz et al., 2006).

Figure 2.1.1 The relationship between ecosystem services and human well-being.



Source: UNEP 2007

groundwater will grow as drought frequency increases in many parts of the world (Tir and Stinnett, 2012). Indeed, global water demand is projected to increase by 55 percent by 2050, further straining the supply (Haddeland *et al.*, 2014; and WWAP, 2015). In semi-arid regions, including the Mediterranean, the demand for water can already exceed availability and supply (EEA, 2012; and Boithias *et al.,* 2014). Scientists predict that by 2025, up to 1.8 billion people could be living with absolute water scarcity and up to two-thirds of the global population could be living under water stress (UNEP, 2007). The decline of this provisioning service is becoming one the most urgent challenges of the 21st century, directly affecting human well-being and indirectly influencing food security and economic stability (Schewe *et al.,* 2014, Bangash *et al.,* 2013; and Elliott *et al.,* 2014).

2.1.2 Food

Food production, another provisioning ecosystem service, is vulnerable to fluctuations in precipitation patterns, temperatures, and climate extremes (Alavian *et al.*, 2009; Müller, 2014). The IPCC's AR5 predicts that yields of major crops such as maize, rice, and wheat will decrease with local temperature increases of 2° C or more over late-20th-century levels. However, these projections vary among crops and across regions, "with about ten percent of projections for the period 2030-2049 showing yield gains of more than ten percent and about ten percent of projections showing yield losses of more than 25 percent compared to the late 20th century" (Porter *et al.,* 2014). Much of this variation is due to biological factors associated with plant growth. Studies have documented a large negative sensitivity of crop yields to extreme daytime temperatures around 30 °C (Porter *et al.,* 2014). A study by Lobell and Gourdji (2012) found that higher temperatures have already reduced wheat and maize yields, but elevated CO^2 has increased yields of C3 crops by over three percent (Ewart *et al.,* 2014). Indeed higher atmospheric CO^2 concentrations may accelerate photosynthesis rates and reduce the amount of water required per unit biomass, boosting crop yields (Porter *et al.,* 2014; Fezzi *et al.,* 2015). Further, increased temperatures will accelerate crop growth and lengthen the growing season (Fezzi *et al.,* 2015). Climate change has already led to variations in the seasonal timing of crops (Visser *et al.*, 2015). To date, many high latitude regions have experienced positive trends in crop production (Porter *et al.,* 2014). Thus, it has been argued that climate change may increase provisioning services in developed countries, while reducing the service in developing counties (Lee, 2009). However, even within a country significant variation could occur.

Women collecting water from dry river bed in Turkana, Kenya.

Photo Credit: Zinta Zommers

Farmers working in fields, Burkina Faso.

Photo Credit: Zinta Zommers

In a study of UK agricultural ecosystem service, Fezzi and others (2014) find that climate change could increase farms' gross margins in Northern Ireland, Scotland, and Wales, factors such as low temperatures in these areas currently discourage plant growth. In southern and eastern England climate change will exacerbate drought problems (Fezzi *et al.,* 2014).

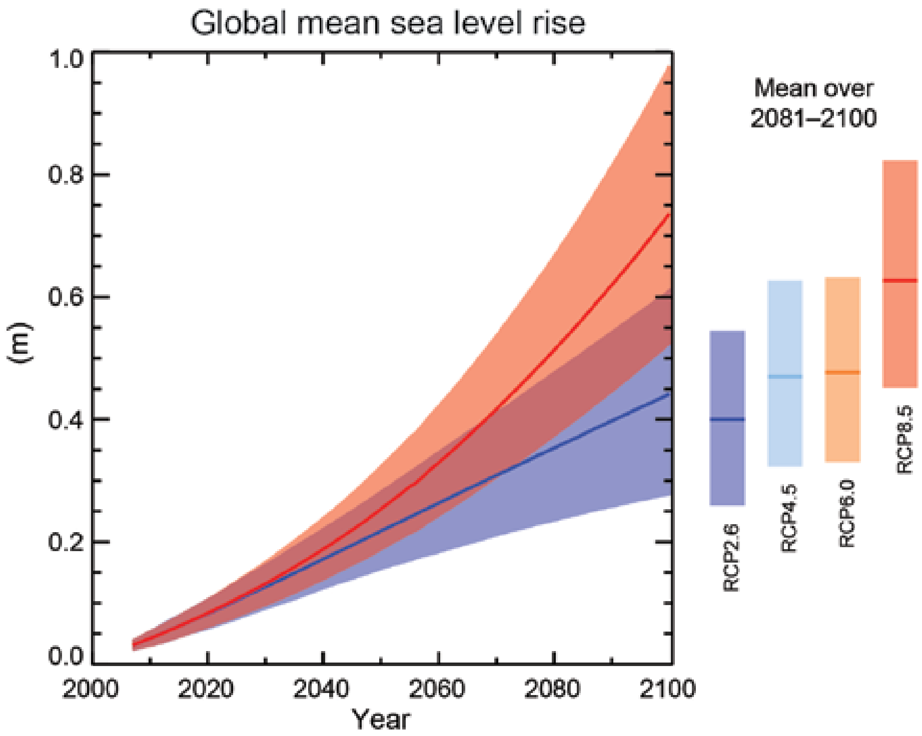
Other studies suggest the impacts of climate change on provisioning services and farm income may be managed successfully through policy interventions or changes in agricultural practices. For example, Sonneveld and others (2012) conclude that in West Africa, reduced rainfall and increased rainfall variability will diminish the yields of maize and yams but improve the yield of cash crops such as cotton and peanuts. With the correct incentives, expansion of cotton plantings could compensate for climate change-related income losses, although overall impacts on human well-being are unclear as various pressures on food security may accrue. Much depends on the scale of adaptation efforts, but hard limits will also exist. According to AR5 "Global temperature increases of 4° C or more about late 20th century levels, combined with increasing food demand, would pose large risks to food security globally and regionally."

2.2 Examples of climate change impacts on regulating services

2.2.1 Flood regulation

Global sea-level rise–the results of rapid ice sheet melt in Greenland and West Antarctic and of changes to seawater including temperature, salinity, and density–is one of the major consequences of climate change (Church *et al.*, 2010). The sea level rise projected to accelerate throughout the 21st century and beyond will inundate low-lying coastal areas and coastal ecosystems will deteriorate as flooding and erosion proceed (Boelee, 2011 and IPCC, 2014). Coastal flooding is already a major problem in many parts of the world. Flood events in San Francisco Bay, for example, were ten times more frequent in the second half of the 20th century than the first half (Woodworth *et al.,* 2010). Specific local effects of future sea-level rise are hard to predict. Global, regional, and local factors must be considered including isostatic motion of the earth's crust or geological factors such as compaction or loss of coastal sediments. The consequences of rising sea levels will be felt acutely through changes in the intensity and frequency of extreme events that variously combine effects of high tides, storm surges, surface waves, and flooding rivers"

Figure 2.2.1 Projections of global mean sea level rise over 21st century.



Source: IPCC (2013)

(Woodworth *et al.,* 2010). For instance, Booji (2005) predicts that in the Meuse river basin in Europe will see a small decrease in the average discharge but an increase in variability and extremes of discharge. Regardless of the specific direction of change, it is clear that climate change will affect the ecosystem service of flood regulation.

2.2.2 Disease Regulation

Climate change will also affect human health, particularly in relation to infectious disease such as malaria, salmonellosis, cholera, and giardiasis (Wu *et al.,* 2016). Climate change disrupts temperature, precipitation, and wind speeds that influence the generation and distribution of infectious disease pathogens and their vectors. For example, as temperatures rise, insects currently constrained to warmer regions may extend their range to higher latitudes and altitudes. But hard limits exist as well. The development of the malaria parasite (*Plasmodium falciprum* and *Plasmodim vivax*) stops between 33 to 39° C (Wu *et al.,* 2016). Ryan *et al.* (2015) used physiological responses of the mosquito malaria vector *Anopheles gambiae* to map future distribution of *P. falciprum* malaria in Africa. The authors predict that modest increase in the overall area suitable for malaria transmission, but an overall decrease in the human population at highest risk for malaria. Another study predicts a decreased length of malaria season in West Africa, in part due to an overall drying and warming trend resulting from human degradation of vegetation rather than climate change (Ermert *et al.,* 2013). The authors note that, many factors affect malaria infection and some counteract the effects of climate change (Ermert *et al.,* 2013). These include economic development, finance for malaria control, and increased distribution of insecticide-treated bed nets. But in East Africa, higher temperatures are predicted to lead to longer transmission seasons and an increase in highland malaria (Ermert *et al.,* 2013). Finally, changes in the frequency of extreme weather may affect disease outbreaks, although with mixed results or associations (Wu *et al.,* 2016).

2.3 Example of climate change impacts on supporting services

2.3.1 Primary Productivity

Climate change is also affecting ecosystem productivity. Many organisms are responding to global warming by shifting their distribution ranges and altering their phenological cycles such as growing, breeding, flowering, hatching, migrating, and hibernating (Hurlbert and Liang, 2012; Visser *et al.*, 2015). The effect of climate change on net primary productivity (NPP) has been assessed, with mixed results. Some studies indicate warming will increase global NPP while others predict NPP decreases. These different results may reflect

Field in Burkina Faso.

Photo Credit: Zinta Zommers

seasonality (Wang *et al.,* 2016). In the summer, most arid and semi-arid regions of China show a negative correlation between temperature and NPP, while in the spring the correlation may be positive in certain regions. Temperature rise strengthens evapotranspiration and reduces soil moisture, which can result in drought and can limit growth during the summer. The authors found that an increase in precipitation is more beneficial to plant growth (Hao *et al.,* 2016). Liu *et al.* (2014) found that changes in extreme events also affect NPP. A vicious winter storm and extremely low temperatures in early 2008 resulted in a drastic decrease of NPP in forest and grass ecosystems in China's Hunan province (Liu *et al.,* 2014). Studies related to primary productivity, as with disease and flood regulation and food production, may indicate that trends and fluctuations related to climate change and extreme events have different, very locally specific, impacts on ecosystem services.

2.4 Example of climate change impact on cultural services

Cultural services comprise a range of largely non-consumptive uses of the environment including the spiritual, religious, aesthetic, and inspirational wellbeing that people derive from the natural world; the value to science of an opportunity to study and learn from that world; and the market benefits of recreation and tourism. Coral reefs offer an example of potential consequences of climate change for cultural services provided by ecosystems. Bleaching events in the past three decades have already caused declines in coral across the Great Barrier Reef (Ainsworth *et al.,* 2016). Global warming and ocean acidification are likely to result in the widespread loss of coral reefs within a century (Hoegh-Guldberg *et al.,* 2007). Coral reefs are an important draw for tourism and source of recreation in many coastal countries (Hoegh-Guldberg *et al.,* 2007). Lane *et al.* (2015) conclude that climate change "could result in a significant loss of value associated with the diverse ecosystem services these habitats provide, including tourism, commercial harvest, and existence (i.e. non-use values)." However, the effects are complex. Tourism itself–including boating, snorkelling and diving–can damage reefs (UNEP, 2016) and there is evidence that reefs may have a natural ability to tolerate stress. Ainsworth *et al.* (2016) conclude:

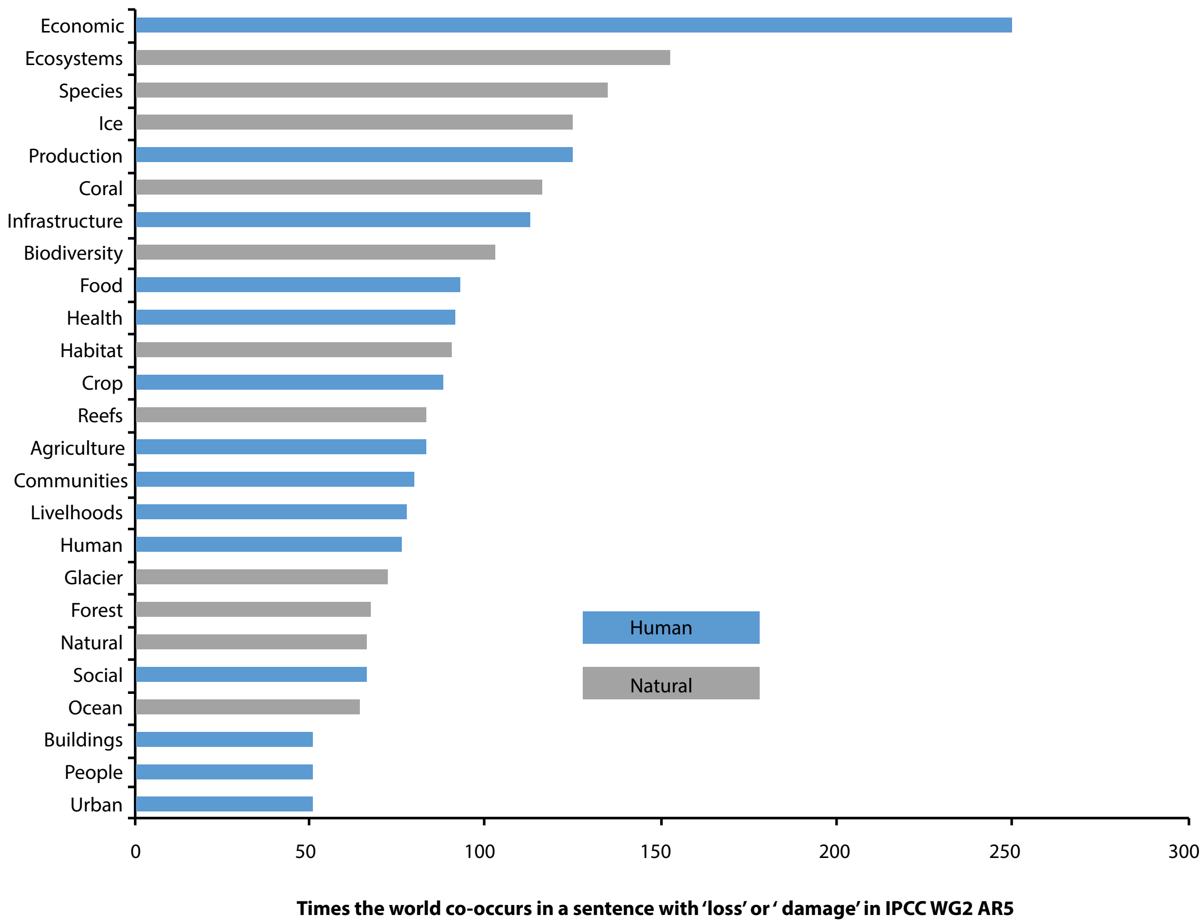
Our analysis reveals that the exposure to sub-lethal pre-stress events varies dramatically among reefs, with some having an inherent level of 'protection from' or 'preparedness for' the conditions that induce coral bleaching, whereas others experience multiple stress

exposures in a single event. Recognizing such spatial variability is important when targeting management actions that aim to mitigate coral reef degradation in the future.

2.5 Loss and Damage to ecosystem services

It is clear that climate change affects many different ecosystem services, sometimes with positive and often with negative outcomes. To further assess negative impacts, a recent report analyzed discussion of different types of loss and damage in IPCC WG2 AR5 (van der Geest and Warner, 2015). The authors assessed how often words associated with different types of impacts occur in one sentence with the words 'loss' or 'damage'. The authors found that impacts on natural (the grey bars) and human systems (the blue bars) receive similar levels of attention in the AR5 report. Within natural systems, the AR5 report focuses attention on species, habitat, and biodiversity. Marine ecosystems are discussed more than terrestrial ecosystems. Loss or damage to ecosystem services is not specifically assessed. AR5 largely frames loss and damage in the context of either natural or human systems rarely making the link between the two (see also Zommers *et al.*, 2014). This relationship between needs to be further explored.

Figure 2.5.1 Loss and damage to natural vs human systems.



The threshold for inclusion in figure is set at 50. Words used in connection to impacts on human as well as natural systems were excluded from the figure.

Source: Van der Geest & Warner (2015)

3. Case Studies: exploring climate change, loss and damage to ecosystems services and human well-being

Studies highlighted in Chapter 2 show that climate change impacts on ecosystem services are often highly localized. This chapter uses several specific case studies to further explore conceptual links between climate change and loss and damage to ecosystem services, and consequently to human well-being. The following questions are broadly explored by the case studies:

1. What was the weather-related event or stressor and did climate change play a role?
2. How did the stressor affect ecosystems and the services they provide?
3. How did the change in ecosystem services affect human systems?
4. What were the adaptation options, and how effective were these at avoiding loss and damage?
5. What is the evidence of loss and damage?
6. What could be done in terms of better preparedness or adaptation to avoid future loss and damage?

3.1 Extreme temperatures and flooding in India and Pakistan

In recent years, India and Pakistan have experienced temperature and flood extremes. Both kinds of extreme events have likely been influenced by anthropogenic climate change. Global warming is expected to deliver more frequent and intense heat waves (Fischer and Knutti 2015), and a general increase in extreme precipitation events (Hirabayashi *et al.*, 2013) as a warmer atmosphere can hold more moisture (Allen and Ingram, 2002).

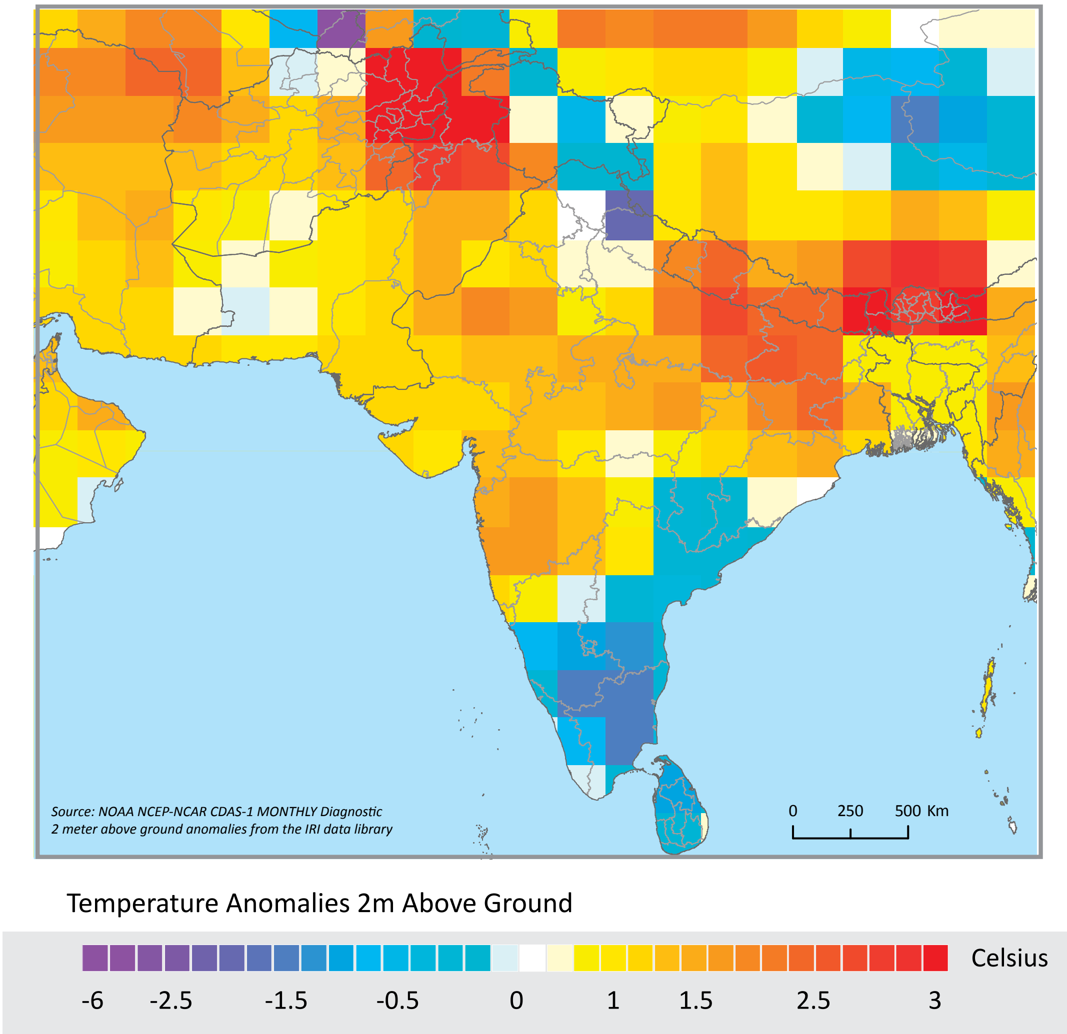
Initial research to link climate change to the specific extreme rainfall in India and Pakistan has had mixed results. Wang and others (2011) found that increased convective activity in Pakistan prior to a major flood event in 2010 flooding was consistent with expected increases in heavy rainfall events over northern regions. However, the 2010 flood was associated with a number of unusual circulation features, complicating any clear link to climate change. Christidis and others (2013) were not able to reliably model the event for an attribution study. Singh and others (2014) suggest that anthropogenic forcing increased the probability of high precipitation in northern India in 2013, but observational records are limited making it difficult to quantify the role of climate change. In many cases, the lack of historical data limits ability to examine whether the specific weather patterns that generated precipitation extremes were influenced by anthropogenic emissions. However, it is well established that climate change is increasing the probability of extreme precipitation events in which intense rainfall is concentrated in short downpours (PIK, 2015; Climate Central, 2014; IPCC, 2012), suggesting that where the atmospheric circulation patterns are aligned for heavy rainfall, the rainfall intensity may be more extreme than it would have been in a cooler atmosphere. Clearly, more research is needed to disentangle the drivers of each event, and understand if they might become more likely in future.

In monsoon regions such as South Asia, the weather follows a seasonal pattern in which temperatures are highest just prior to the monsoon season—May in the case of India and Pakistan—and then decrease slightly with the onset of the monsoon. The 2015 pre-monsoon season was characterized by unusually high temperatures on the Gangetic Plain along the border between India and Nepal and in Punjab province of Pakistan (Figure 3.1.1).

In early June, temperatures in Patna, India, a city of 1.4 million people along the Ganges, exceeded long-term average temperatures that were already very high, by 2° C for more than 10 days, with maximum temperatures of 44° C (Figure 3.1.2). These temperatures test the physiological limits of the human body to dissipate heat; the pre-monsoon heat wave resulted in an excess of more than 1,800 deaths (Weber and Brink, 2015). Extreme temperatures also damage natural vegetation and wildlife through desiccation of natural areas, drying of watering holes, and changes in animal behaviour, ultimately degrading ecosystem services that regulate natural systems to provision and support human systems. While no single extreme event can be attributed solely and unequivocally to climate change, this kind of extreme is consistent with the IPCC's AR5 finding that high temperature extremes are effectively certain to be hotter and to occur more frequently this century.

Extreme temperatures such as those experienced in India and Pakistan put poor populations particularly at risk of morbidity and mortality for a number of reasons. Many are day labourers who cannot afford to not work, or may be required to work, during periods of extreme heat. In addition, they are the least able to afford air conditioning, and are more likely to live in densely settled slums with poorer ventilation in housing units and less tree cover.

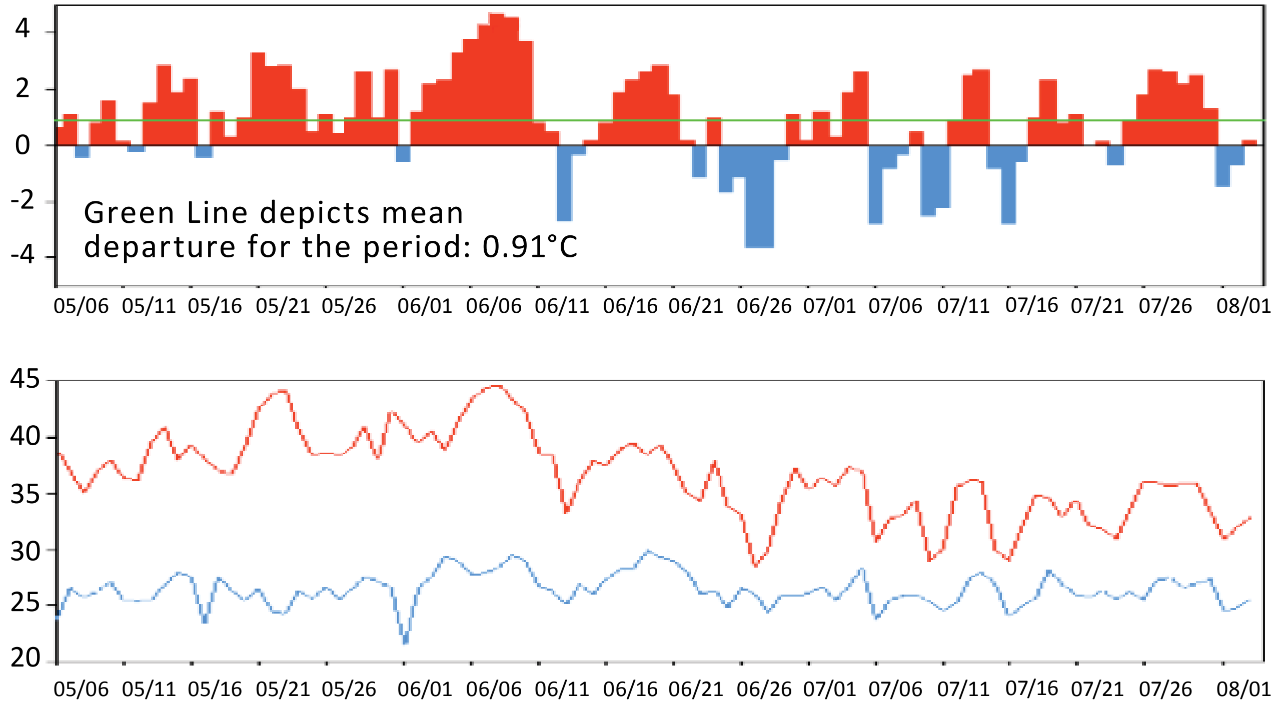
Figure 3.1.1 Temperature anomalies in South Asia for May 2015.



Traditional adaptation strategies for extreme heat include building designs for hot climates, such as mudbrick construction instead of cement with zinc roofs, and afternoon siestas or periods of rest. There are constraints to adaptation measures, however: In India it was reported that many poorer workers continued to work through the hottest part of the day, in fear they would lose their jobs, and this leads to increased morbidity. Short of building cooling centers for the poor on a massive scale, ecosystem-based approaches to adaptation suggest that planting trees and developing shaded areas, where poor citizens can escape the heat, replicate the regulating service of ecosystems at appropriate scales. Research on urban heat islands has clearly demonstrated the importance of green space for reducing urban heat stress (Wilhelmi *et al.,* 2012).

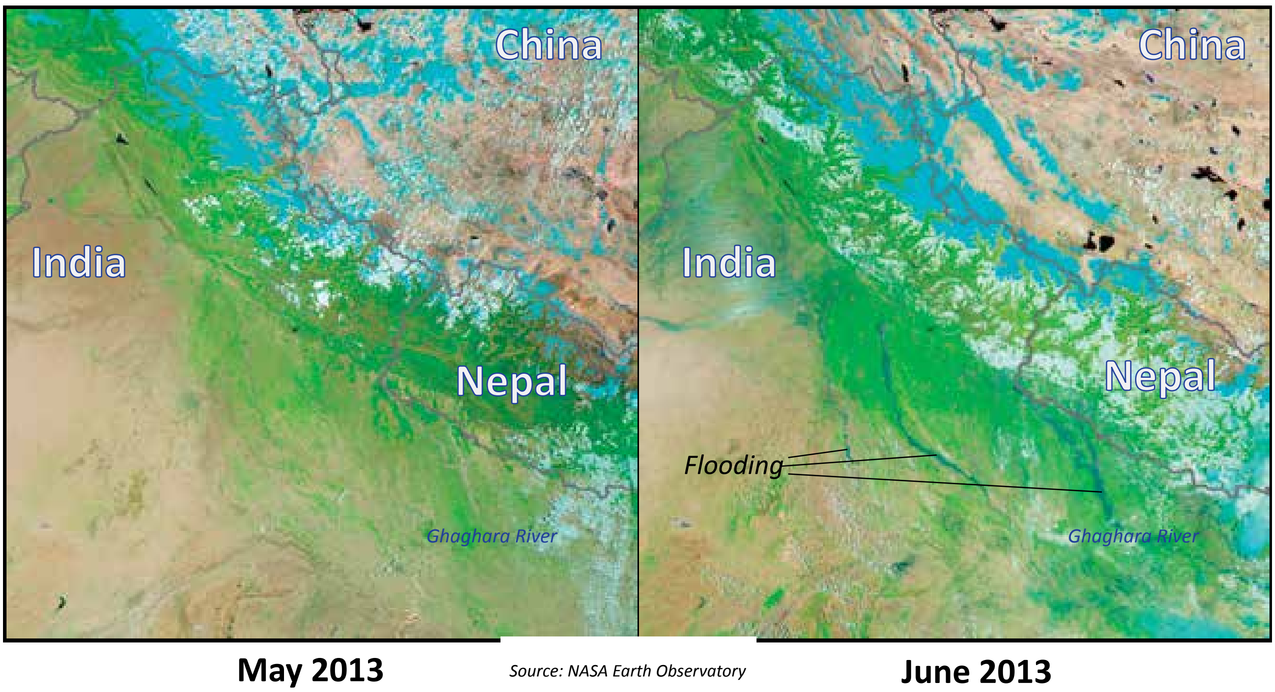
In addition to temperature extremes, both India and Pakistan have experienced increasing numbers of devastating flood events. In fact, every year or two, regions of both countries experience major flood events. Evidence suggests that flood frequency has increased since the 1980s along riverbanks and low-lying areas, partly as a result of changing precipitation extremes and partly owing to changes in land cover (Davis, 2014; Guha-Sapir and Hoyois, 2014). Forest loss and increases in paved surfaces have depleted the regulatory service previously provided by vegetation and soils in river catchments. After the extreme heat of May-June 2015, July brought major flooding to many parts of India. The floods cause infrastructure damage, loss of dwellings, loss of personal property, and loss of human life. They also increase riverbank erosion and carry away topsoil, impairing the supporting ecosystem service of soil formation. Torrential rains undermine slope stability and contribute to landslides in hilly regions. Landslides can lead to ecosystem losses such as reduction in pastureland, as well as destruction of homes, roads, and infrastructure. In mountainous North India, 2013 floods caused major landslides and riverbank erosion (Figure 3.1.3). In Kedernath, Uttarakhand Province, a

Figure 3.1.2 Temperature anomalies in Patna, India from 6 May – 5 August 2015.



Source: NOAA 2015

Figure 3.1.3 Satellite imagery for May 2013 (left) and June 2013 (right) showing extent of flooding (dark blue) along the Nepal-India border.



Source: NASA Earth Observatory

combination of intense rainfall and a glacial lake outburst flood nearly destroyed the town and its temple, a major Hindu pilgrimage site (Upton, 2014; Grossman, 2015).

Pakistan has been similarly affected. In July 2015, heavy monsoon rains, rapid snow melt, and outbursts from glacial lakes led to flash floods and flooding along the Indus River and its tributaries (OCHA, 2015). As devastating as the 2015 floods were, from July to September 2010 the worst floods in Pakistan's history affected the entire Indus River Basin with widespread destruction (Figure 3.1.4). In late July, extreme rainfall events dumped close to 500 mm in catchments of the Indus and Jhelum Rivers (Masters, 2010). More than 20 million people were affected, with a death toll of 1,781, damage to 1.89 million homes, and major crop and livestock losses (ReliefWeb, 2010). While one study could not find evidence to suggest that this event was directly attributable to climate change (Christidis *et al.*, 2013), the IPCC AR5 and Special Report on Managing the Risks of Extreme Events (IPCC, 2012) agree that extreme rainfall events are more likely in a warmer climate owing to the ability of the atmosphere to hold more moisture.

Adaptation to flooding involves both ecosystem approaches and physical infrastructure. Ecosystem approaches include re-vegetation of catchments, wetland creation and restoration, and preservation of floodplains for agriculture and grazing lands. Physical infrastructure involves water regulation through dams and reservoirs as well as canalization. However, increasingly the sheer volume of water arriving at one time can overwhelms physical infrastructures installed to control the water. Where infrastructure installations are breached, the destructive power of floods can multiply because the existence of flood control infrastructure often spurs development along flood plains. In 2005 damage from Hurricane Katrina was so severe in New Orleans and surrounding areas of the Mississippi delta partly as a result of such factors. In mountainous regions, sudden and intense precipitation events produce raging rivers that are difficult to predict or control. Theoretically the best remedy is to locate housing and other infrastructure at a safe difference from floodplains—a difficult proposition in regions where valley floors are easier to develop. At the same time, attention should focus on development along or near steep slopes that are composed of unconsolidated materials, where slope collapse is most likely to occur.

Figure 3.1.4 Flooding in Pakistan as of 30 August 2010.

Source: U.S. Department of State, Humanitarian Information Unit

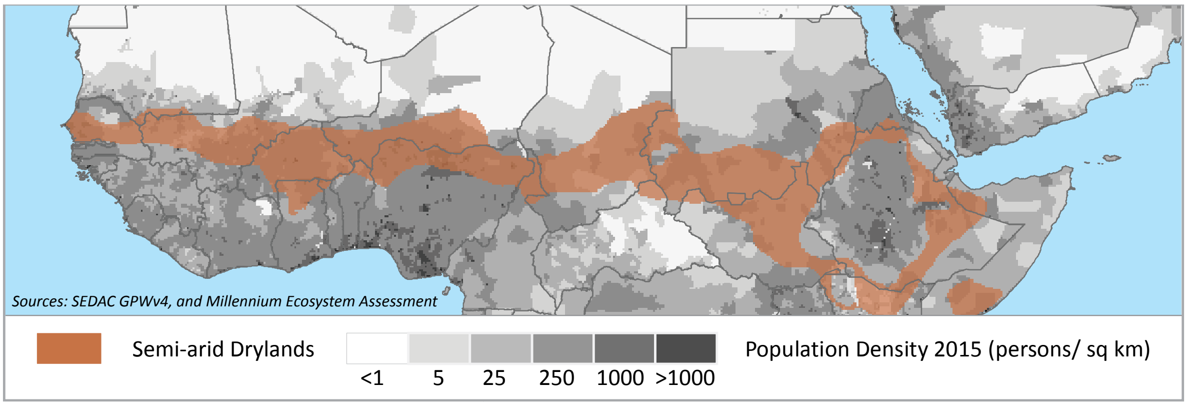
3.2 The drylands of the Sahel and East Africa

The Sahel and the semi-arid drylands of East Africa are in many ways emblems of climate change vulnerability. The regions have faced challenges such as crop and livestock losses, food insecurity, displacement, cultural losses including traditional livelihood systems, and conflict. Many of these challenges are caused by climate variability and exacerbated by climate change. At the beginning of 2015 an estimated 20.4 million people were food insecure as a result of ongoing drought—mostly in Niger, Nigeria, Mali, and Chad where conflict and poverty compound food insecurity (ReliefWeb 2015).

transpiration from vegetation. Therefore, even in places where rainfall increases, it may not be sufficient to offset overall moisture loss, affecting primary productivity and food production, which are supporting and provisioning ecosystem services respectively.

In the drylands of Africa, rainfall is characterised by high variability from year to year, and even from decade to decade. Figure 3.2.3 shows the rainfall variation for the Sahel from 1951-2013. Large areas of the drylands have inter-annual rainfall variability that is +/- 30 percent of the mean. During the 1970s and early 1980s the Sahel experienced a long and widespread drought that was

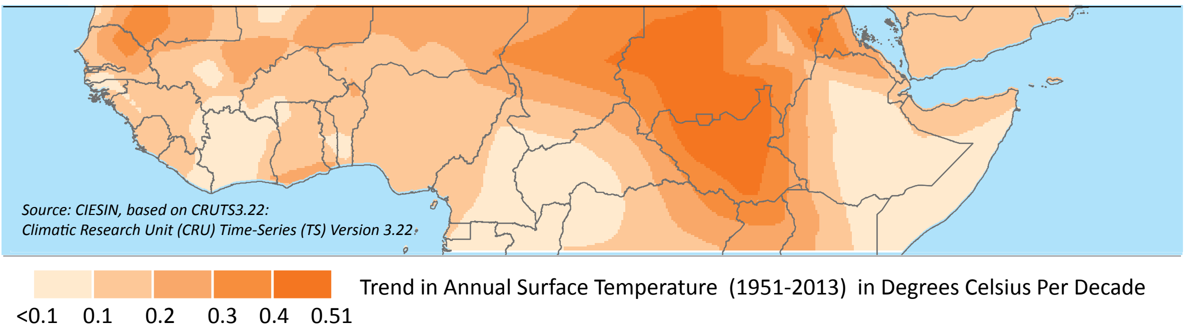
Figure 3.2.1 Semi-arid Drylands and Population Density of the Sahel and East Africa.



A number of changes are occurring in the region. For one, it is becoming hotter, and this is clearly consistent with climate change. Temperature increases vary widely within the region, but range to as much as 0.5° C per decade from 1951 to the present (or 3.5° C total) in a large part of Sudan, and are also high, 0.2° C to 0.4° C per decade, in large parts of Mauritania, Mali, Niger, Chad and Uganda (Figure 3.2.2). Recent studies suggest that in some African regions warming is occurring at more than double the global and tropical average (Cook and Vizy 2015; Engelbrecht *et al.,* 2015). Higher temperatures increase evaporation from soil and water surfaces and

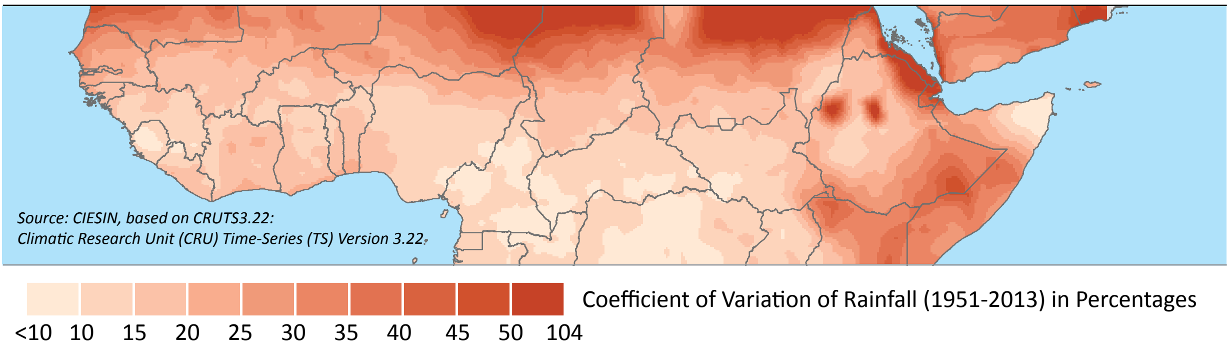
associated with a devastating famine (Held *et al.* 2006; Conway *et al.* 2009). Trends for the late 20th and early 21st century suggest an increase in the intensity and length of droughts in West Africa (IPCC, 2012), and a decline in rainfall of between 10-20 percent, with rainfall becoming less dependable (Turco *et al.*, 2015). These statistics may not indicate a continuous change given the large decadal variability and the droughts in the middle of this period. Nevertheless, pronounced shifts in rainfall are evident. For example, in the drylands of Mali and Burkina Faso, the number of years that exceed the minimum required to grow sorghum and millet has changed over

Figure 3.2.2 Temperature change in degrees Celsius per decade from 1951-2013.



Notes: Trends are obtained by adjusting a linear trend to inter-annual anomalies (anomalies with respect to the 63 yr average), with no other filtering (not removing any other scales of variability). It is expressed in degrees C/decade.

Figure 3.2.3 Coefficient of variation of rainfall from 1951-2013 (in percent of the long term average).



time (Figure 3.2.4). During the period 1950-69, generally recognised as an anomalously wet period for the Sahel, there was reliable rainfall for sorghum and millet in many regions, but in recent decades the number of years that met the threshold was 60-80 percent lower. This demonstrates how climatic variability and change can threaten ecosystem services: in this case the ability to grow food.

Research on loss and damage from the 2004 and 2010 droughts in northern Burkina Faso showed that villagers have become less able to cope with droughts because of a decline in pastoralism and an increase in cropping (Traore and Owiyo, 2013). For millennia, herders moved their livestock where pasture was more abundant, a way of life that brought resilience to droughts. With recent land use change policies, severe barriers to pastoralists' freedom of movement make them more vulnerable to droughts. Surveys found 96 percent and 87 percent of respondents felt the negative effects of droughts on crops and livestock, respectively, and that extreme droughts tend to have cascading effects. First, the lack of water affects seedling growth and crop yields, which then affects the availability of food for people and feed for livestock (Traore and Owiyo, 2013).

Temperature increase, rainfall unpredictability, and land use changes also affect the Lake Chad basin. Once among Africa's largest lakes, home to abundant fisheries and supporting livestock herds, Lake Chad has shrunk from 25,000 sq. km in 1963 to around 1,000 sq. km (Figure 3.2.5) (UNEP 2008). A ridge that emerged during the drought in the 1970s and 1980s now divides Lake Chad in two. Despite the recovery of rainfall in the 1990s, the lake never fully recovered because irrigation withdrawals increased from the primary tributaries to the south, where rainfall is higher (Gao *et al.* 2011). The lake once supported a vital traditional culture of fishing and herding. As the lake receded, farmers and pastoralists shifted to the greener areas, where they compete for land resources with host communities (Salkida 2012). Others have migrated to Kano, Abuja, Lagos, and other big cities. The decline of Lake Chad illustrates how changing climate patterns interact with other anthropogenic modifications and poor governance to result in loss and damage.

In other parts of the Sahel, rainfall recovery in recent decades has brought flooding because the rainfall arrives in more intense cloudbursts rather than more frequently (Giannini *et al.* 2013). In 2007, for example, rainfall extremes and consequent flooding led to crop

Figure 3.2.4 Difference in the number of years that received adequate rainfall for sorghum and millet.

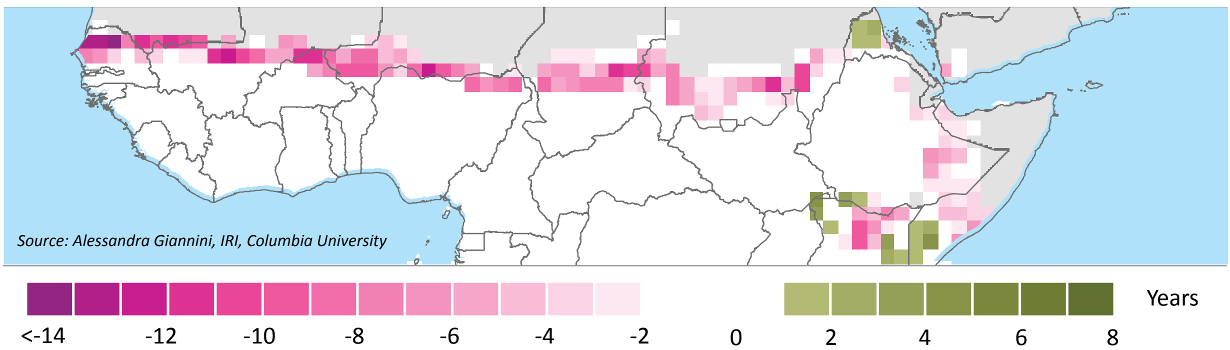
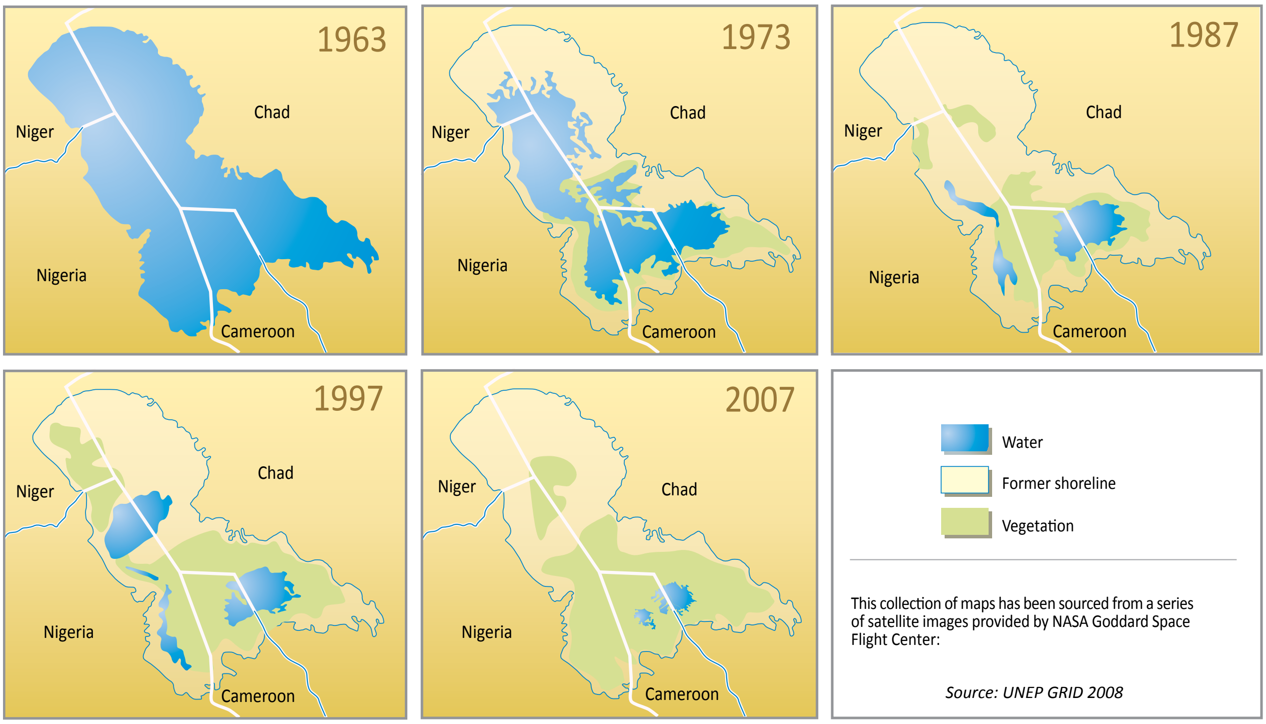


Figure 3.2.5 The shrinking of Lake Chad.

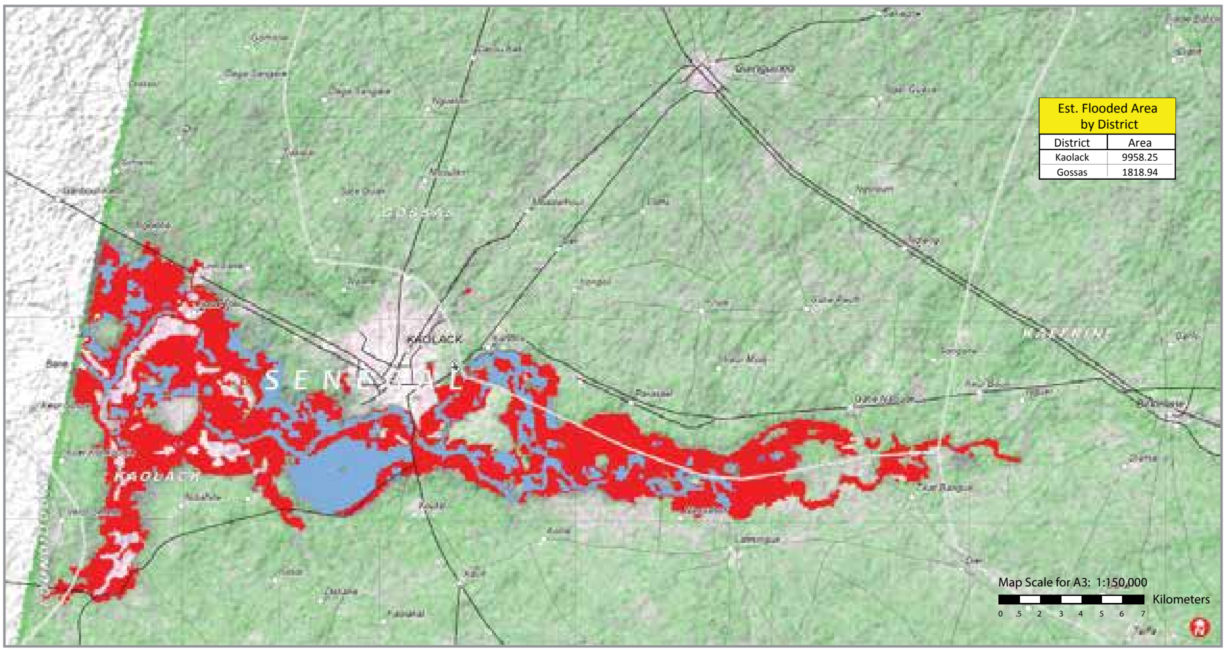


loss in Senegal's peanut basin because farmers often cultivate in and around natural depressions, in addition to loss of property (Figure 3.2.6). Research in eastern Senegal on household perceptions of flood and drought indicate that climate variability brings crop, livestock and other economic losses (Miller *et al.* 2014). Over the past decade, on average households reported experiencing two and a half to three years of drought and 0.2 to 0.5 years with flooding, with higher incidence in the north than the south.

It is unclear how climate change might influence the Sahel in future, with some sources of evidence suggesting there might be a shift to wetter conditions while other evidence suggests that conditions will become much drier (Druyan *et al.* 2011). Thus, there are questions about the influence of human-induced climate change in the region, yet there is ample evidence to demonstrate the vulnerability to climate shocks, as well as potential shifts in climate.

While Sahel rainfall is dominated by one monsoon season in June to September, many parts of the drylands in East Africa experience two rainy seasons, the long rains of approximately March to June and the short rains of approximately October to December. From 1980 to 2010, precipitation in the long rains has decreased in some dryland areas by up to 180 mm (Figure 3.2.7) and this has been linked to a series of devastating droughts (Lyon and DeWitt 2012, Viste *et al.* 2013, Liebmann *et al.* 2014, Rowell *et al.* 2015). Together with land degradation (Figure 3.2.8), this has led to increased food insecurity in the region. Losses in ecosystem services such as soil moisture retention and primary productivity reduce local resilience to drought, and may also lead to landslides, gullying, and sheet erosion during extreme rainfall events. In 2011 the region experienced a particularly destructive drought. In Kenya, 3 million people required immediate assistance during the most intense period and 45,360 head of cattle were lost (Desinventar 2015). In the Horn of Africa as a whole, the drought affected over 8 million people and provoked a refugee crisis (EM-DAT database). That drought has been associated with warming in the West Pacific and Indian Ocean (Funk 2012). This is consistent with predictions that human-induced climate change leads to pronounced warming in the Indian Ocean (Lott *et al.* 2013). However, other climate models suggest that East Africa will become wetter in future, so there is some uncertainty about the influence of global warming on this region (Rowell *et al.* 2015)

Figure 3.2.6 Flooding in the peanut basin south of Kaolack, Senegal (September 2007).



Source: UNOSAT 2007

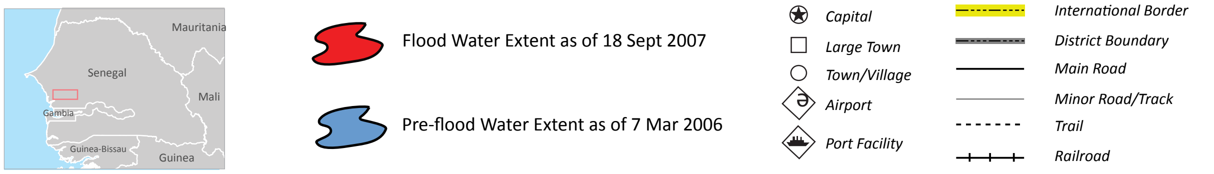
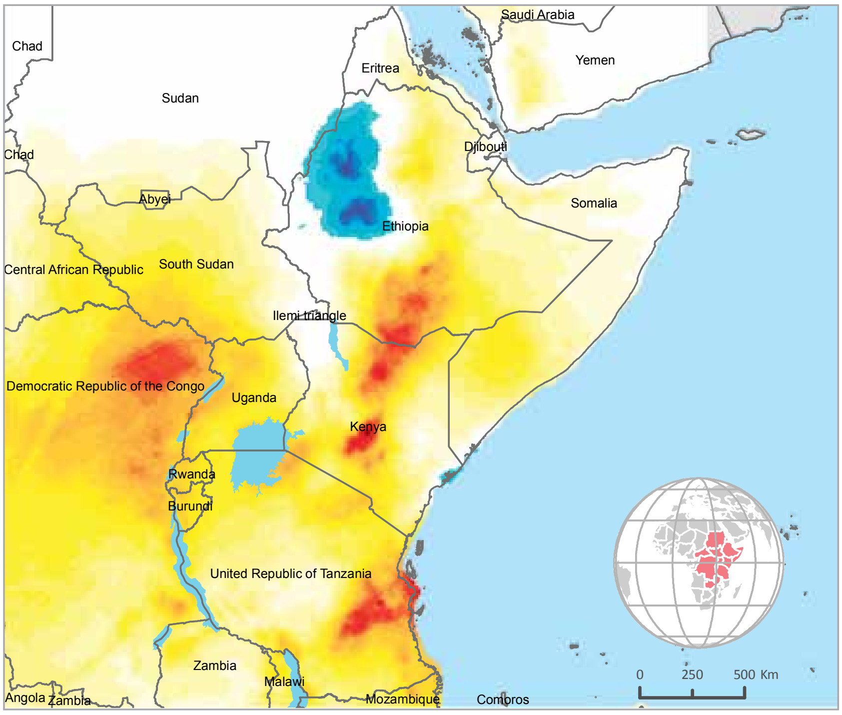


Figure 3.2.7 Changes in rainfall from 1981-2010 for the April – June rainy season.



Source: CIESIN, based on CHIRPS FCLIM

Linear Trend in Seasonal Precipitation for April to June Rainy Season from 1981–2010 (mm/year)

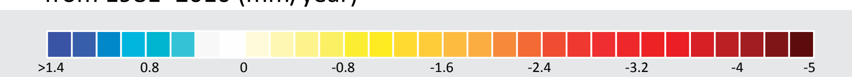
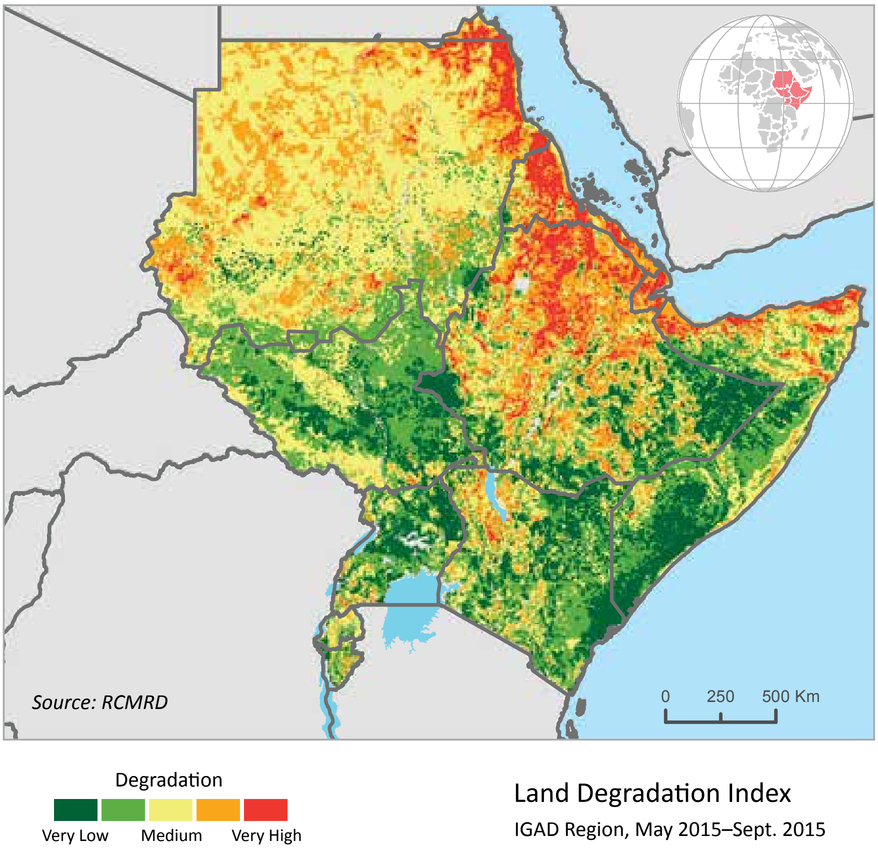


Figure 3.2.8 Land degradation in drylands of East Africa from May-Sept 2010.

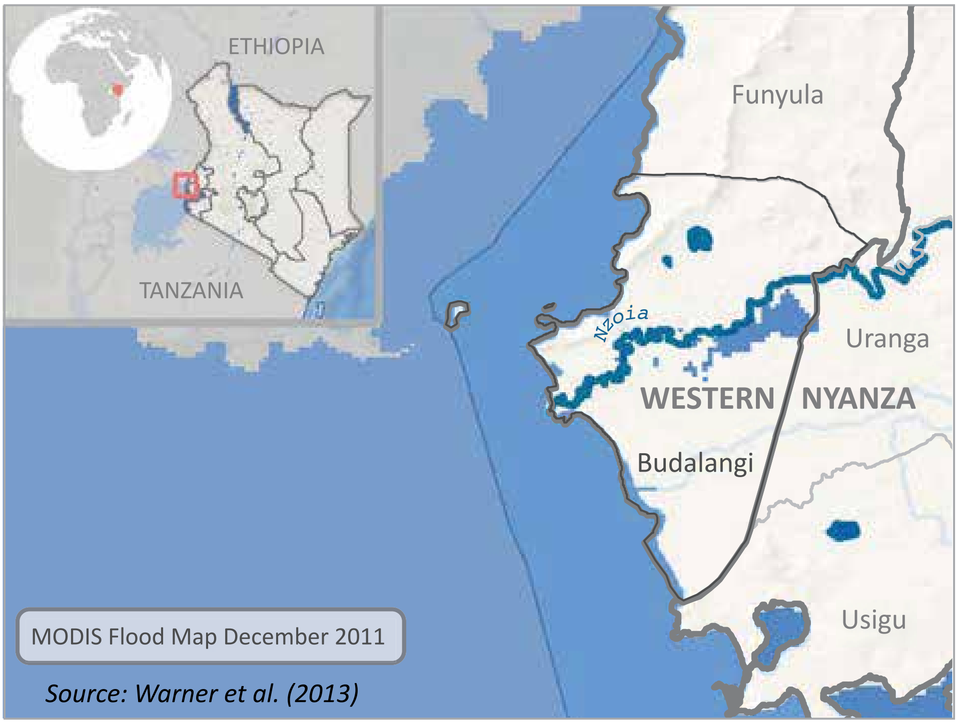


Source: Regional Center for Mapping of Resources for Development (RCMRD)

The drought of early 2011 was succeeded by intense rainfall, producing floods in many parts of Kenya that resulted in additional and extensive losses of crops and livestock (Opondo, 2013). In December 2011, River Nzoia in Western Kenya broke its dykes and caused havoc in Budalangi Division (Figure 3.2.9). Crops were washed away, livestock drowned, houses were severely damaged, and there was an outbreak of waterborne diseases. Flooding in this low-lying area on the shores of Lake Victoria is not a new phenomenon. However, floods have become more frequent and intense over the past decades. Empirical research in the affected areas showed that many of the coping measures that households adopted to deal with flood impacts had short-term benefits but adverse effects in the longer term (Opondo, 2013; Warner and van der Geest, 2013). An example of such erosive coping behaviour was the sale of draught animals to buy food. The following season, the bullocks were not available to plough the fields and people's situation became even more precarious. This example illustrates how losses from extreme events can have indirect and mid- to long-term consequences for household assets.

Adaptation measures implemented in the Sahel and the East Africa drylands include crop-livestock integration, soil fertility management, planting of drought-resistant crops, water harvesting, dug ponds for watering animals, livelihood diversification, and seasonal or permanent migration. A number of these methods have been practiced for generations and are the norm for these semi-arid regions. However with changing climate such practices will have to be scaled up or new methods developed, as adaption has not been sufficient to prevent losses. New methods include index-based insurance, in which payouts to participating farmers and herders are not made on the basis of actual losses but on the basis of changes in rainfall or drought indices, thereby reducing the overhead of claims inspections. This has been tested successfully in Senegal, Ethiopia, and northern Kenya (Greatrex *et al.*, 2015).

Figure 3.2.9 Floods in western Kenya, December 2011.



Source: Warner et al. (2013)

In the future, temperature changes may create real limits to adaptation, for example, where temperature increases are beyond the limit of crops during critical points in their life cycle (Ericksen *et al.*, 2011). According to the IPCC, in Africa "climate change combined with other external changes (environmental, social, political, technological) may overwhelm the ability of people to cope and adapt, especially if the root causes of poverty and vulnerability are not addressed" (Niang and Ruppel, 2013).

3.3 The European heat wave

During the summer months of 2003 large parts of Europe were affected by a major heat wave. According to WMO (2011) this heat wave was likely the hottest since at least 1540. The heat wave has also been seen as a "shape of things to come," reflecting temperatures that are extreme now, but projected as normal summer temperatures in the later 21st century (Beniston and Diaz, 2004). The effects on humans were severe, partly because the affected population was not acclimatized to such temperature extremes.

The IPCC defines a heat wave as "a period of abnormally and uncomfortably hot weather" (IPCC 2013). According to the IPCC AR5, it is likely that the frequency of heat waves has increased in large parts of Europe, Asia, and Australia and that human influence has more than doubled the probability of heat wave occurrence in some locations. Heat waves have important implications for ecosystems, for example, by constraining carbon and nitrogen cycling and reducing water availability, with the result of potentially decreasing production or even causing mortality in some species (Handmer *et al.*, 2012). Yet ecosystems can also provide important regulatory services on climate. In urban areas, the limited vegetation and concentration of building materials, with thermal and properties that absorb and re-radiate heat, can generate an urban heat island effect. Thus cities are significantly warmer than surrounding rural areas due to human activities. This effect can exacerbate heat waves, and has been associated with large death tolls for the elderly, the unwell, the socially isolated, and outdoor workers (Maloney and Forbes 2011, Handmer *et al.*, 2012).

During the 2003 European heat wave, average June to August temperatures reached five standard deviations above the long-term mean, demonstrating that this was an extremely unusual event (Schär and Jendritzky, 2004). The average temperatures in summer 2003 exceeded the 1961-90 seasonal mean by 2.3° C: the summer was 20 to 30 percent warmer than usual (Stott *et al.*, 2004). The heat wave extended from northern Spain to the Czech Republic and from Germany to Italy; however, France was affected the most. For instance, between the 4th and 12th of August maximum daily temperatures recorded in Paris remained mostly in the range of 35 to 40° C, while minimum temperatures

Figure 3.3.1 Heat Wave map: Evolution of heat wave in summer 2013.

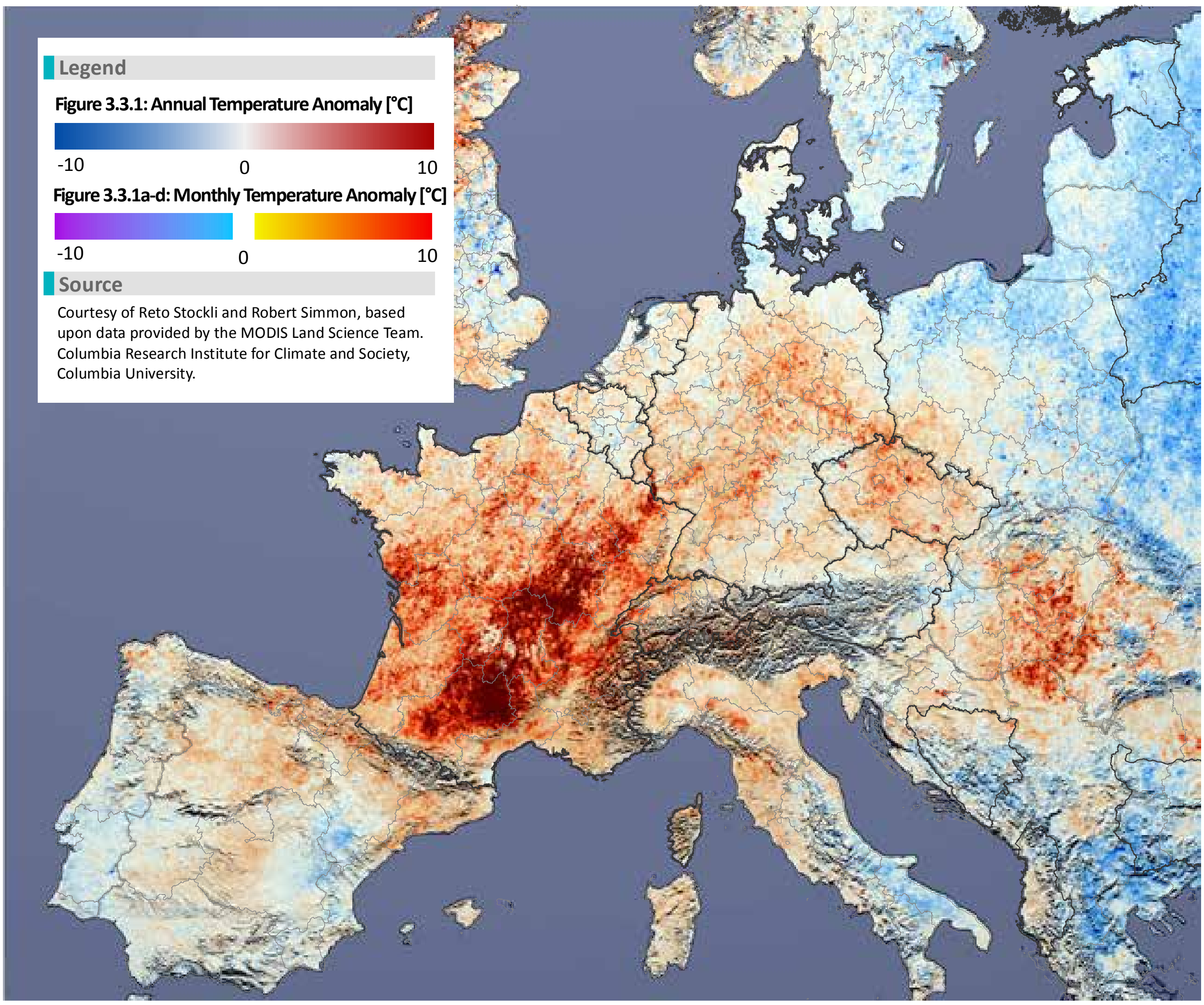


Figure 3.3.1a - Temperature Anomaly May 2003

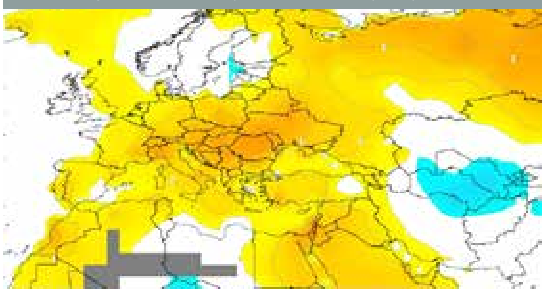


Figure 3.3.1b - Temperature Anomaly June 2003

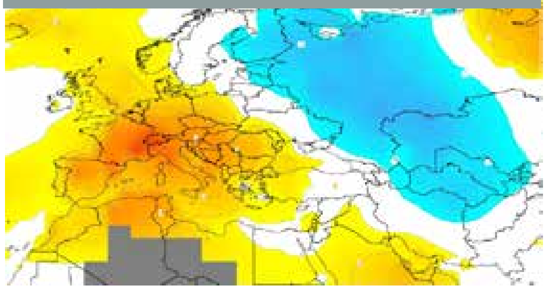


Figure 3.3.1c - Temperature Anomaly July 2003

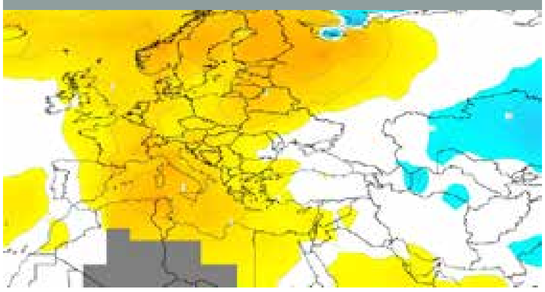
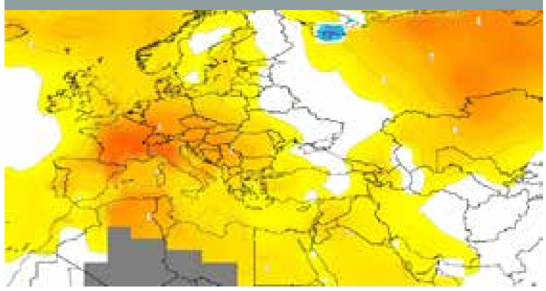


Figure 3.3.1d - Temperature Anomaly August 2003



recorded by the same weather station remained almost continuously above 23° C between 7th and 14th of August (Météo France, 2003). The event was associated with a very robust and persistent blocking high pressure system that some weather services suggested may be a manifestation of an exceptional northward extension of the Hadley Cell (Beniston and Diaz, 2004). This situation was exceptional in the extended length of time–over 20 days–during which very hot dry air arrived from south of the Mediterranean.

The 2003 heat wave was the subject of the first formal extreme event attribution study (Stott *et al.* 2004), the first to investigate the role of climate change in a specific weather event to estimate whether anthropogenic emissions affected the probability of occurrence. These researchers found that human activity had at least doubled the probability of generating a heat wave above this threshold, with more than 90 percent confidence.

Of course, there are uncertainties associated with this estimate, however, more recent studies also suggest that human influence has dramatically increased the probability of heat waves of this magnitude. In fact, with the benefit of new models and observations Christidis and others (2015) suggest that the anthropogenic contribution to the 2003 heat is much greater than the doubling reported by Stott and others (2004). They also find an increased risk since the early 2000s: "events that would occur twice a century in the early 2000s are now expected to occur twice a decade."

The heat wave in 2003 is perceived as one of the ten deadliest natural disasters in Europe for the last 100 years. Consequences directly affected humans, and indirectly affected human systems and ecosystem services by driving higher energy demands, higher water stress with low river water levels reducing the efficiency of thermal power plants, economic losses for the agriculture sector, a significant decrease in glacier volumes, and damage to montane permafrost through increased thawing (UNEP DEWA 2004). As such, the European heat wave had significant consequences, affecting both humans and the ecosystem services that are crucial for humans in the short as well as the long term.

Natural environment and agriculture

The heat wave impaired provisioning services, including food production and water supply. The uninsured economic losses for the EU agriculture sector were estimated at € 13 billion (Sénat, 2004). A record drop in crop yields of 36 percent occurred in Italy for maize grown in the Po valley in Italy, where extremely high temperatures prevailed (Ciais *et al.*, 2005). Based on the findings of UNEP, over all of Europe the main agriculture sectors hit by the extreme climate conditions were the green fodder supply, the arable sector, the livestock sector, and forestry. The heatwave triggered a record Alpine glacier loss that was three times above the 1980–2000 average (Haeberli *et al.* 2007), continuing a long-term and accelerating pattern of mass loss (Zemp *et al.* 2006). According to Keiler and others (2010), the main factors for this remarkable 2003 loss were a reduced snowpack that melted quickly from small- and medium-sized glaciers, exposing older and darker ice. Then the warm dry conditions brought dark particulates and dust to the glacier surfaces, producing an albedo feedback with long-term effects (Paul *et al.* 2005; Haeberli *et al.* 2007; Koboltschnig *et al.* 2009). For instance glaciers in Austria retreated by an average of 23 m, with a maximum retreat of 73 m (Patzelt 2004). Furthermore, the response of permafrost temperature and the thickness of the active layer varied considerably in summer 2003 (Harris *et al.* 2009). The thaw depth in permafrost on bedrock slopes was twice the average of previous years and indicates a strong coupling between atmospheric and ground temperatures (Gruber *et al.*, 2004; Keiler *et al.*, 2010). As a consequence increased rockfall activity was observed throughout the Alps during summer 2003 (Gruber *et al.*, 2004; Fischer *et al.*, 2006).

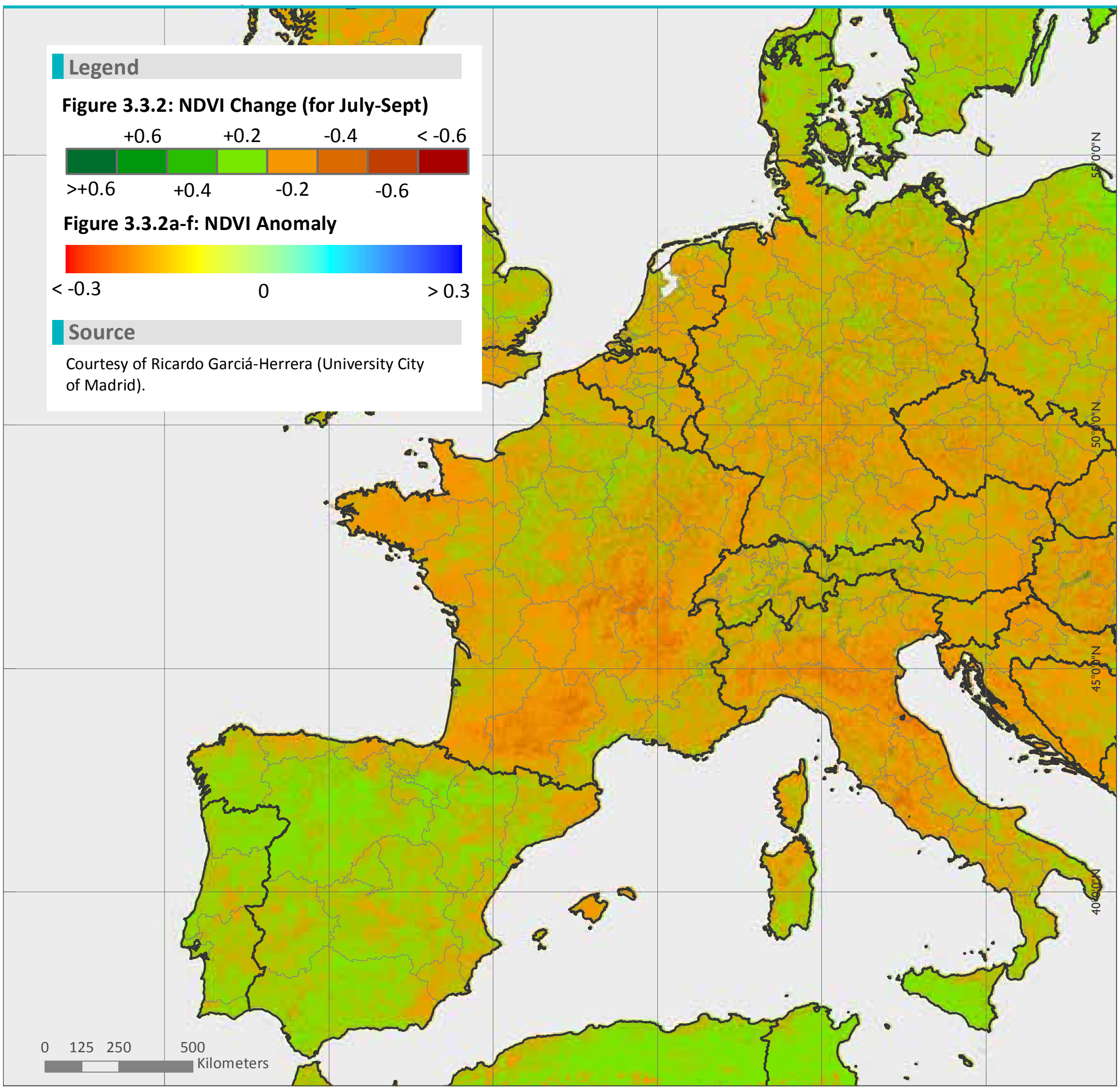
Supporting services such as primary productivity were also influenced. A 30 percent reduction in gross primary productivity, together with decreased ecosystem respiration over Europe during the heatwave in 2003, resulted in a strong net source of CO_2 to the atmosphere and reversed the effect of four years of net ecosystem carbon sequestration. Such a reduction in Europe's primary productivity is unprecedented for at least a century (Ciais *et al.*, 2005).

Ciais and others (2005) suggest that productivity reduction in eastern and western Europe can be explained by rainfall deficit and extreme summer heat. They found that ecosystem respiration decreased together with gross primary productivity, rather than accelerating with the temperature rise. An increase in future drought events could turn temperate ecosystems into carbon sources, contributing to positive carbon-climate feedbacks already anticipated in the tropics and at high latitudes.

The review of the heat wave as conducted by Garciá-Herrera and others (2010) provides also various insights on the impact of primary productivity.

The monthly anomalies of the Normalized Difference Vegetation Index (NDVI) is illustrated for the year of 2003 (Figure 3.3.2). The analysis is based on data from the VEGETATION instrument as installed on the SPOT satellite. The NDVI measures the response of the vegetation in the near-infrared which is directly linked to the amount of existing chlorophyll. Hence, a direct measure of the vitality of the vegetation is derived.

Figure 3.3.2 Environmental impacts: Change of primary production – NDVI, 2003.



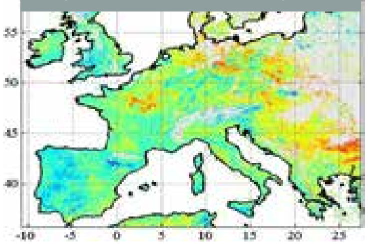


Figure 3.3.2a - NDVI Anomaly March

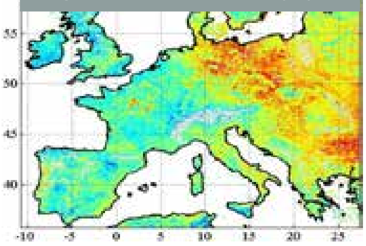


Figure 3.3.2b - NDVI Anomaly April

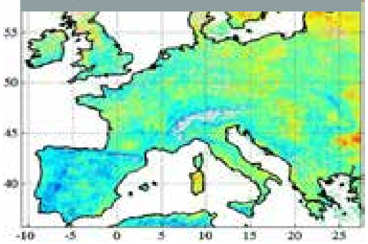


Figure 3.3.2c - NDVI Anomaly May

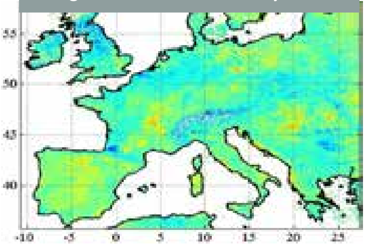


Figure 3.3.2d - NDVI Anomaly June

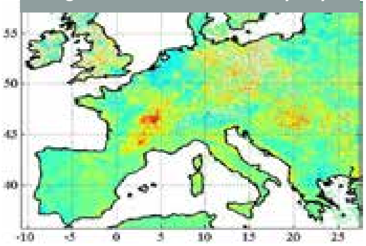


Figure 3.3.2e - NDVI Anomaly July

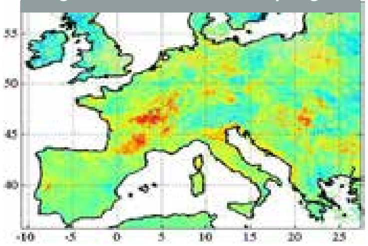


Figure 3.3.2f - NDVI Anomaly August

Figure 3.3.3 Humanitarian Impacts of the heatwave 2003: People died/affected in 2003 in Europe (on admin level). Disaggregated population data to show real population distribution.

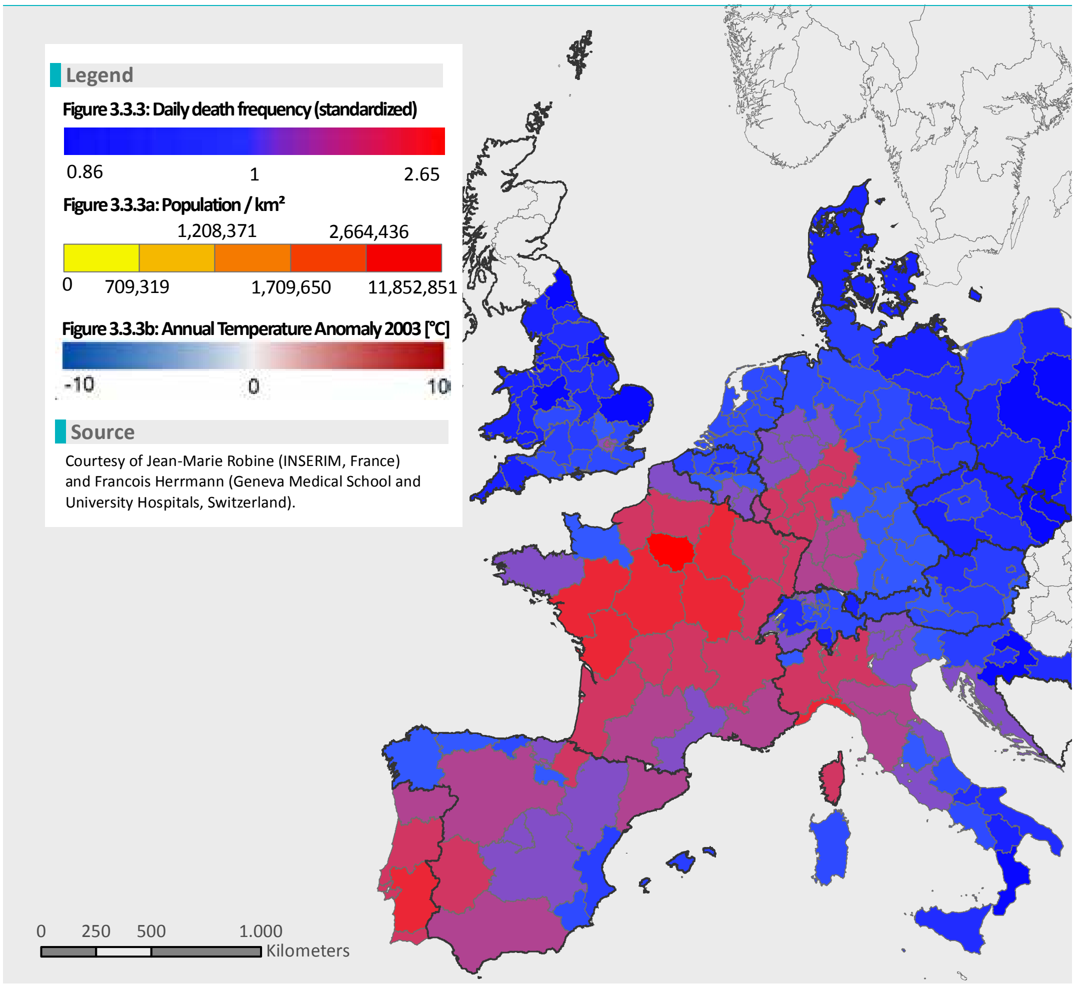


Figure 3.3.3a - Population per km² on NUTS2

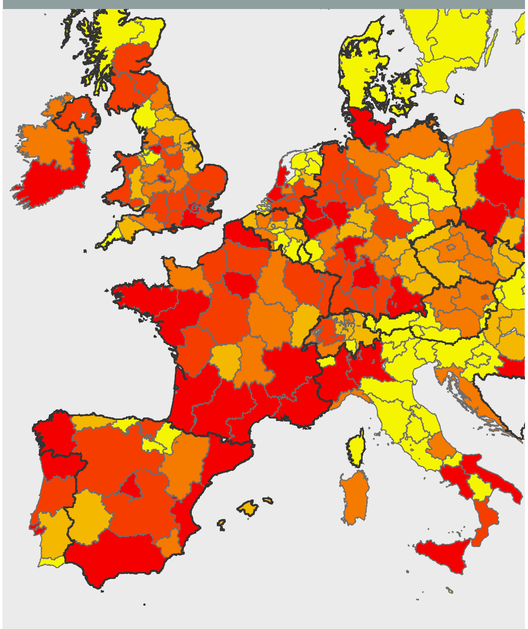
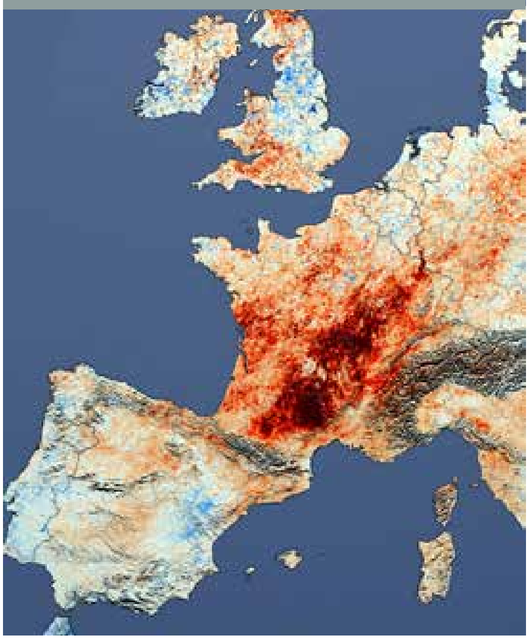


Figure 3.3.3b - Annual Temperature Anomaly 2003 [°C]



Consequences for human health

The European heat wave had significant health impacts (Lagadec, 2004). Initial estimates were of costs exceeding €13 billion, with a death toll of over 30,000 across Europe (UNEP, 2004). It has been estimated that mortality over the entire summer could have reached about 70,000 (Robine *et al.*, 2008) with approximately 14,800 excess deaths in France alone (Pirard *et al.*, 2005) (see Figure 3.3.3).

During the heatwave of August 2003, air pollution levels were high across much of Europe, especially surface ozone (EEA, 2003). A post-event rapid assessment was performed for the United Kingdom. The assessment associated 21 to 38 percent of the total 2,045 excess deaths in the United Kingdom in August 2003 to elevated ambient ozone and PM10 concentrations (Stedman, 2004). The task of separating health effects of heat and air pollution is complex; however, statistical and epidemiological studies in France also concluded that air pollution was a factor associated with detrimental health effects during August 2003 (Dear *et al.*, 2005; Filleul *et al.*, 2006).

3.4 Typhoon Haiyan (Yolanda)

On November 8, 2013, Typhoon Haiyan made landfall in the central parts of the Philippine archipelago. Called Yolanda in the Philippines, Haiyan's maximum sustained winds reached 315 kph with gusts up to 379 kph while still over water (Tajima *et al.* 2014, Lagmay *et al.* 2015). Due to its outstanding severity, Haiyan is referred to as a 'Category 6' storm, overshooting the traditional five levels of the Saffir-Simpson Hurricane scale (Lin *et al.* 2014). Strong winds, heavy rainfall, and storm surges that stood over 5m converged to bring extreme loss and damage to lives and property as well as to ecosystem services (Figure 3.4.1).

Certain weather preconditions are necessary to form a tropical cyclone. These include ocean waters of at least 26.5° C, an unstable atmosphere, low vertical wind shear, and a minimum distance from the equator of at least 500 km (Figure 3.4.2). If these conditions persist for long enough, they can produce a tropical cyclone, known as a typhoon in the North Pacific Ocean. For past trends and future projections, the IPCC's AR5 had low confidence that long-term changes in tropical cyclone activity are likely or that any particular cyclonic event can be attributed to climate change (IPCC 2013).

The lack of evidence is due to insufficient observational data and a lack of understanding of physical links between anthropogenic climate change and drivers of tropical cyclone activity. However, the AR5 concludes that there will be increased rainfall extremes of typhoons making landfall along the coasts of Asia.

For Haiyan, evidence on climate change attribution is yet not clear. The intensity seems to be attributed to two main factors: (i) specific conditions which increased the strength of the typhoon, and (ii) increased sea level rise (Trenberth *et al.* 2015). According to Lin *et al.* (2014) it is suggested that as the western Pacific manifestation of the La Niña-like phenomenon is to pile up warm subsurface water to the west, the western North Pacific experienced evident subsurface warming and created a very favorable ocean pre-condition for Haiyan. Associated with that are stronger winds from the east, which transport warm surface water to the west. A thicker layer of warm water, as well as a high sea level, especially near the Philippines, are the result and create ideal conditions for the formation of a typhoon (Lin *et al.* 2014). Together with its fast traveling speed, the air-sea flux supply was 158 percent as compared to normal for intensification. Trenberth *et al.* (2015) further suggest that the storm surge was undoubtedly exacerbated considerably by the sea levels, which were some 30 cm above 1993 values.

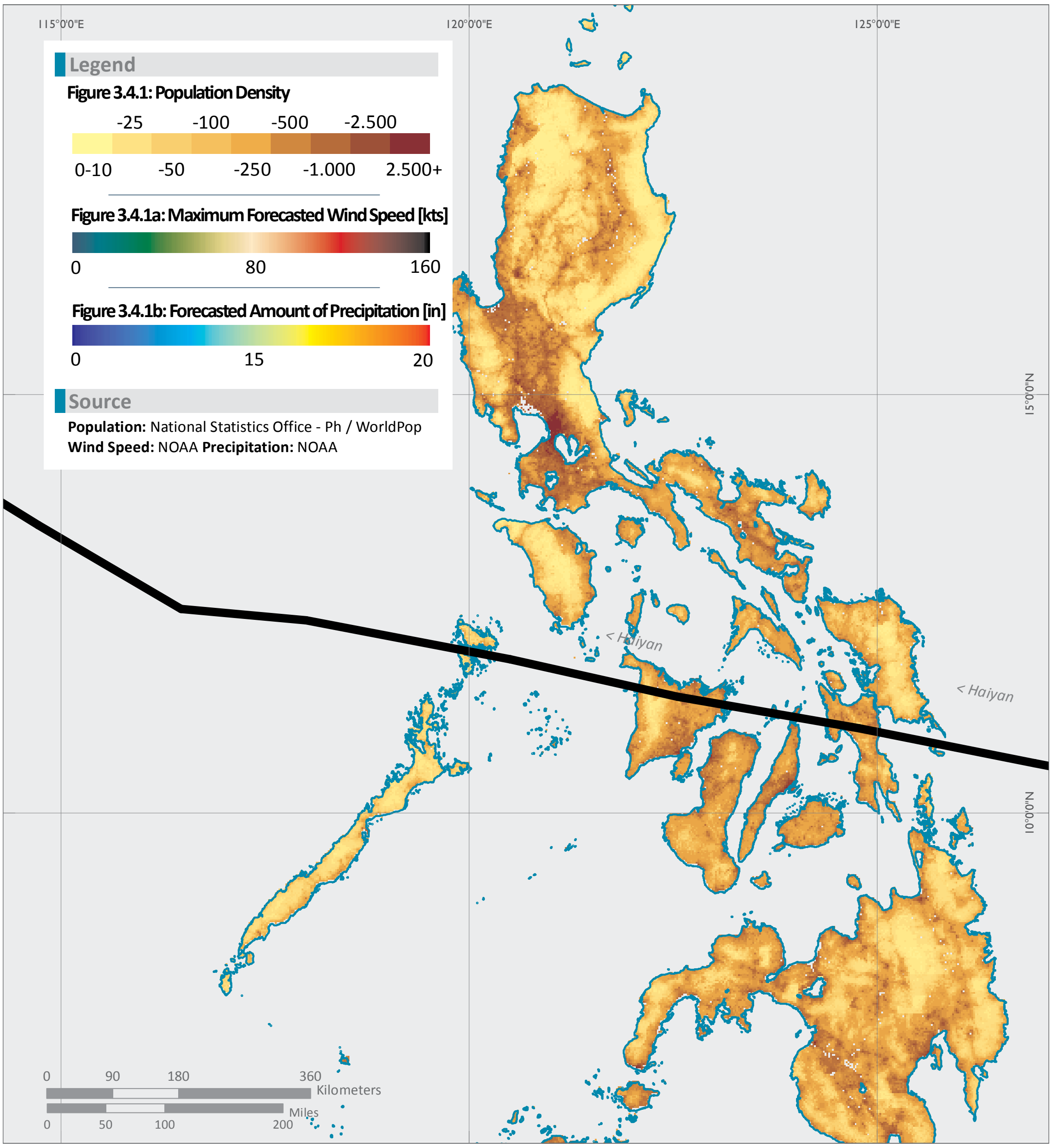
Haiyan caused excessive damage to human lives and livelihoods, with a high death toll, many injuries, and a high number of displaced families. Aside from this direct harm to people, damage to agriculture and ecosystems, especially in coastal zones, indirectly harmed people.

Natural Environment

The Philippines is classified as a megadiverse country. It does not only contain a high proportion of global biodiversity, it also has more than 20,000 plants and animal species that are unique to the archipelago. Since 2000, more new mammal species were described than in any other country in the world (Marler 2014). The biodiversity of the Philippines is not only limited to land surface, but includes coastal zones and reefs offshore.

Haiyan caused the most extensive damage to the different species of mangroves, impacting supporting and regulating services. Long and others (manuscript in preparation) used Landsat imagery to calculate the NDVI for the pre- and post-event. The authors then compared the NDVI values (before and after) to estimate the damage to mangroves. As expected, the highest damage follows the eye path of Haiyan (Figure 3.4.1). The affected area of mangroves is estimated to be 214.45km^2, which is about 9 percent of the total mangrove areas of the Philippines. About 6.53km^2 of the mangrove area experienced substantial damage, indicated by a significant decrease in the NDVI (over 0.5). However, it has to be mentioned that not all areas could be included in the analysis, since some parts of the satellite imagery were obstructed by clouds (Figure 3.4.3).

Figure 3.4.1 Typhoon path of Haiyan, Maximum Wind Speed and Amount of Precipitation.



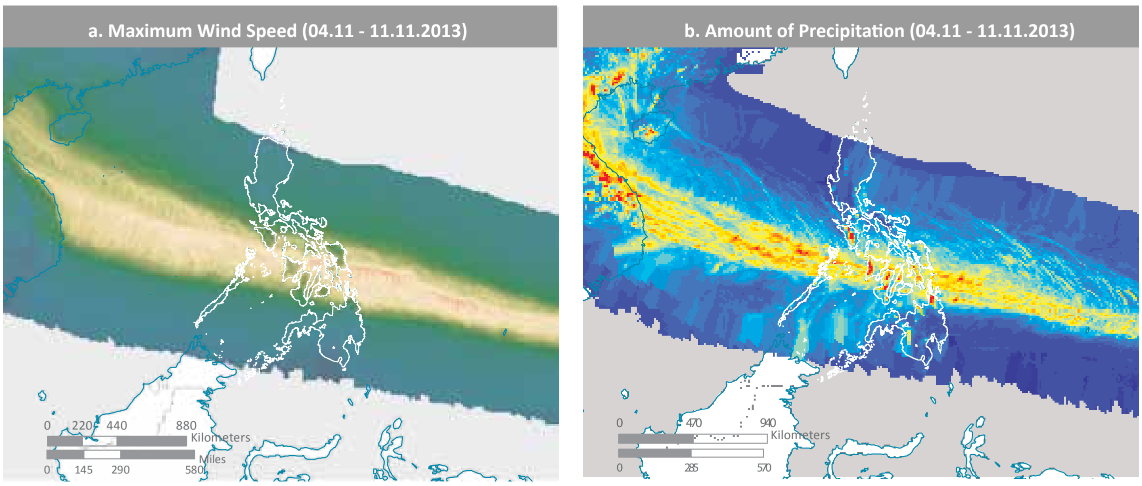


Figure 3.4.2 Tropical Cyclones in the Western Pacific, Tropical Cyclone Heat Potential and Sea Surface Temperature Anomaly.

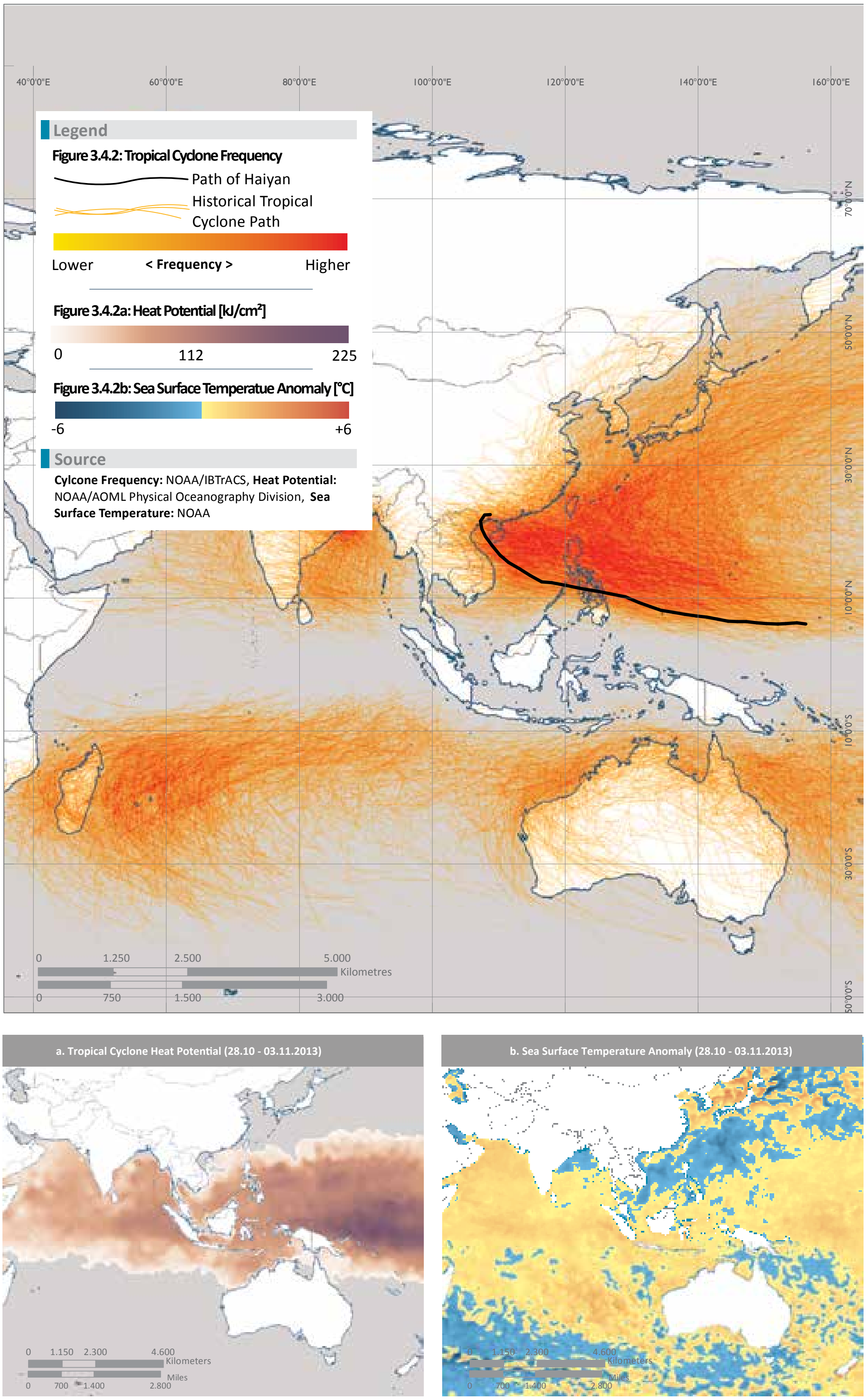


Figure 3.4.3 Impacts to the natural environment: General land cover map, differences in NDVI Pre/Post-Haiyan and marine sites in the Philippines.

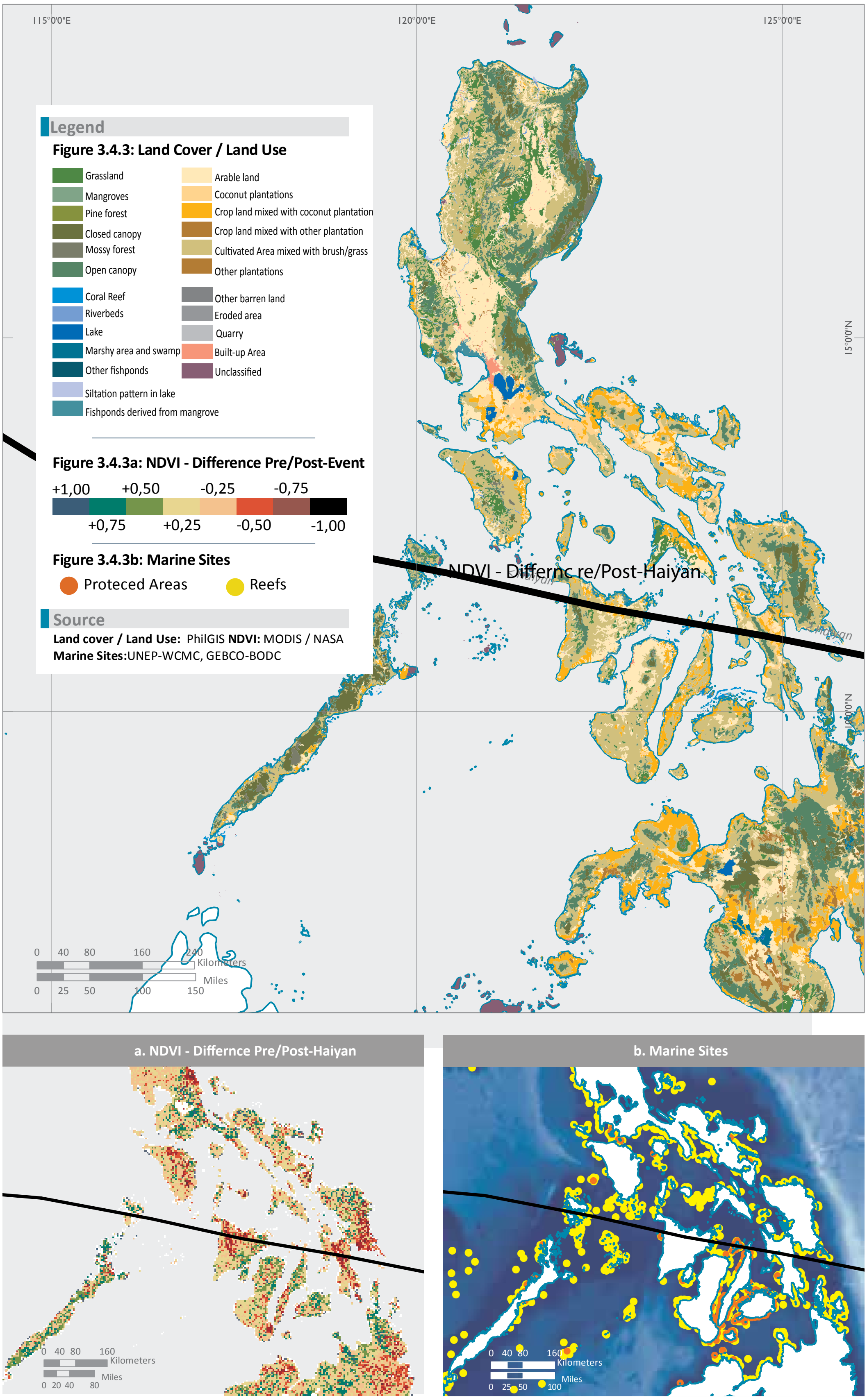
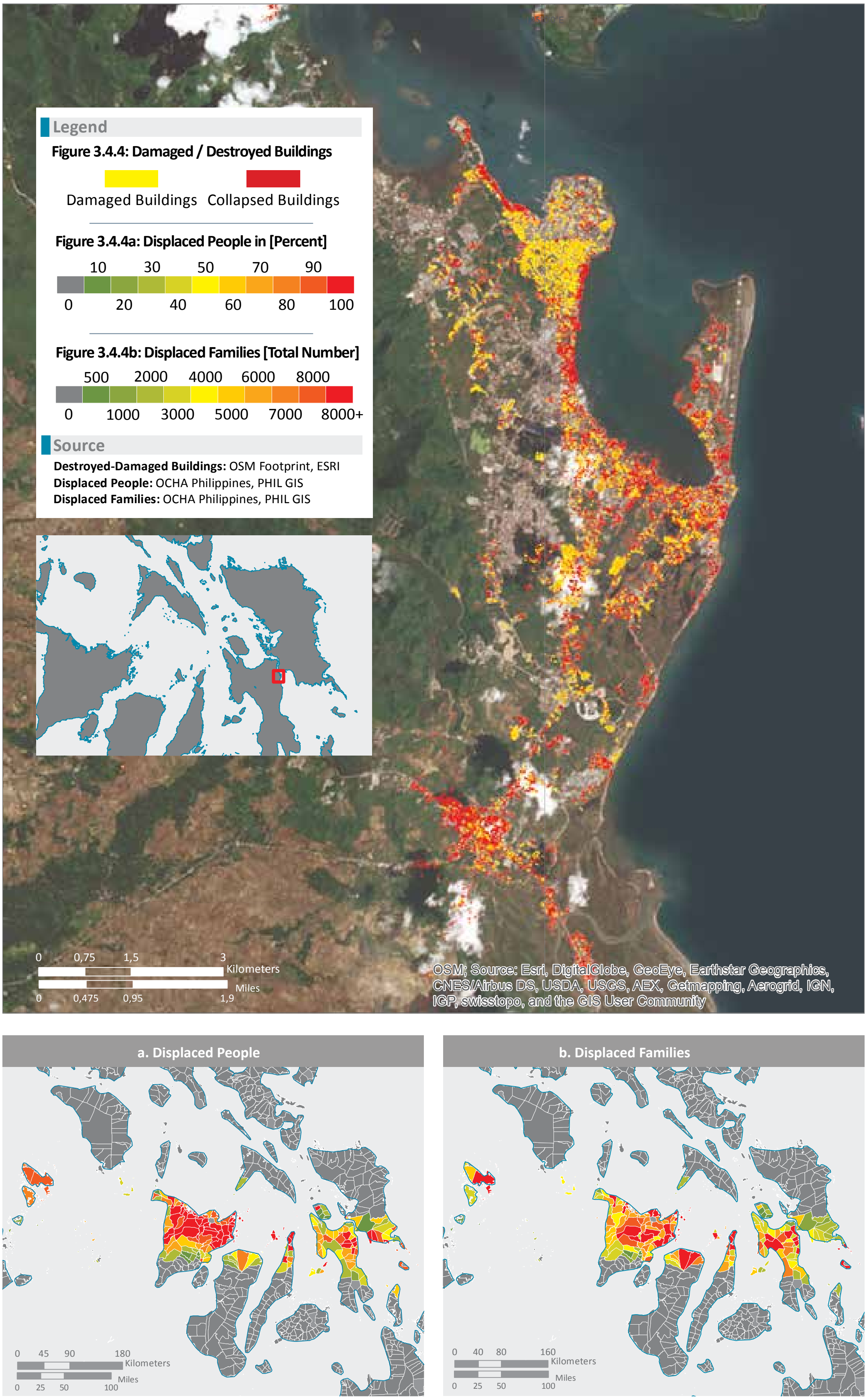


Figure 3.4.4 Typhoon Haiyan and affected people in Tacloban, displaced peoples and families in the Central Philippines.



The heavy winds and massive waves slammed a power barge into the coast of Iloilo resulting in a major oil spill with over 600,000 litres of leaked bunker oil. Over 1,000 families had to relocate because the air pollution reached a critical level as a result of this oil spill. Since most of the oil washed ashore, the mangroves, fisheries and coastline were damaged up to 10km downstream (OCHA, 2014b). The sensitive equilibrium of the coastal coral reefs was also damaged by the oil spill. Furthermore, the direct force of the typhoon damaged coral reefs, which sustain marine ecosystems, particularly in shallow water regions.

Waste dumpsites were a problem in some areas since these emergency dumpsites were created in just a short time and without too much consideration for the environment. As a result of destroyed trees and debris, wildfires ignited sometime after Haiyan and destroyed some parts of hardwood forests (OCHA, 2014b).

Agriculture

The agricultural sector was heavily affected, including not only crop areas but also infrastructure and irrigation systems. About 450,000 farmers and fishing households were directly affected by Haiyan, especially those in the coastal areas (OCHA, 2014). In some regions up to 80 percent of crops were destroyed. About 80,000 of the 4.67 million hectares of rice fields and 30,000 of the 2.57 million hectares of maize fields were lost to the typhoon. In the Visayas region, Haiyan destroyed roughly 24 percent of the seasonal rice and maize yields. However, these losses represent just two percent of the total national rice farmland and one percent of the maize growing areas in the Philippines. The nation-wide food security was not threatened by the typhoon since the most important agricultural areas are located in less damaged areas to the north in Luzon and the south in Mindanao. On the other hand, coconut palm tree plantations, which are particularly important for some regions, were largely destroyed. Over 40 million coconut palm trees were either damaged or destroyed (Figure 3.4.3), leaving debris that introduced a high risk for wildfires. About 440,000 hectares of coconut palm trees were affected, of which 161,400 hectares is considered as totally damaged.

Humanitarian Damage

Over 6,300 people lost their lives due to the typhoon and over 28,000 people were injured. Aside from these immediate deaths and injuries, middle- and long-term impacts were also incurred. Over four million people were displaced. In the city of Tacloban (total population 221,174), almost 59,000 families were affected by the typhoon, over 12,000 houses were destroyed, and 46,000 properties were at least partly damaged (Figure 3.4.4). In this city, 2,048 people lost their lives due to the tropical cyclone. These numbers emphasise the enormous harm to the people in the Philippines due to the Haiyan. Beside the strong winds, the storm surge also damaged and destroyed huge areas at the coastal zones.

3.5 The San Joaquin Valley in the California Drought

Since 2012, California has experienced the most severe drought conditions in its recorded history. The US Drought Monitor identifies the California drought as "exceptional," the most intense category (USDM, 2015). Geoscientists used paleoclimate reconstructions of drought and precipitation for Central and Southern California to define the current drought as the most severe in 1,200 years (Griffin and Anchukaitis, 2014).

California is the most populous state in the US by a large margin, with over 38 million residents (US Census, 2014). The federal Department of Agriculture's 2013 statistics show California accounts for close to 12 percent of national farm commodity value, producing over one-third of the nation's vegetables and two thirds of its fruits and nuts (USDA NASS, 2015). The heart of California's agriculture is the Central Valley, with about 75 percent of the irrigated land in California, and so about 17 percent of the nation's irrigated land. By itself, the Central Valley produces 25 percent of US food, including 40 percent of its fruits, nuts, and table foods (USGS, 2015).

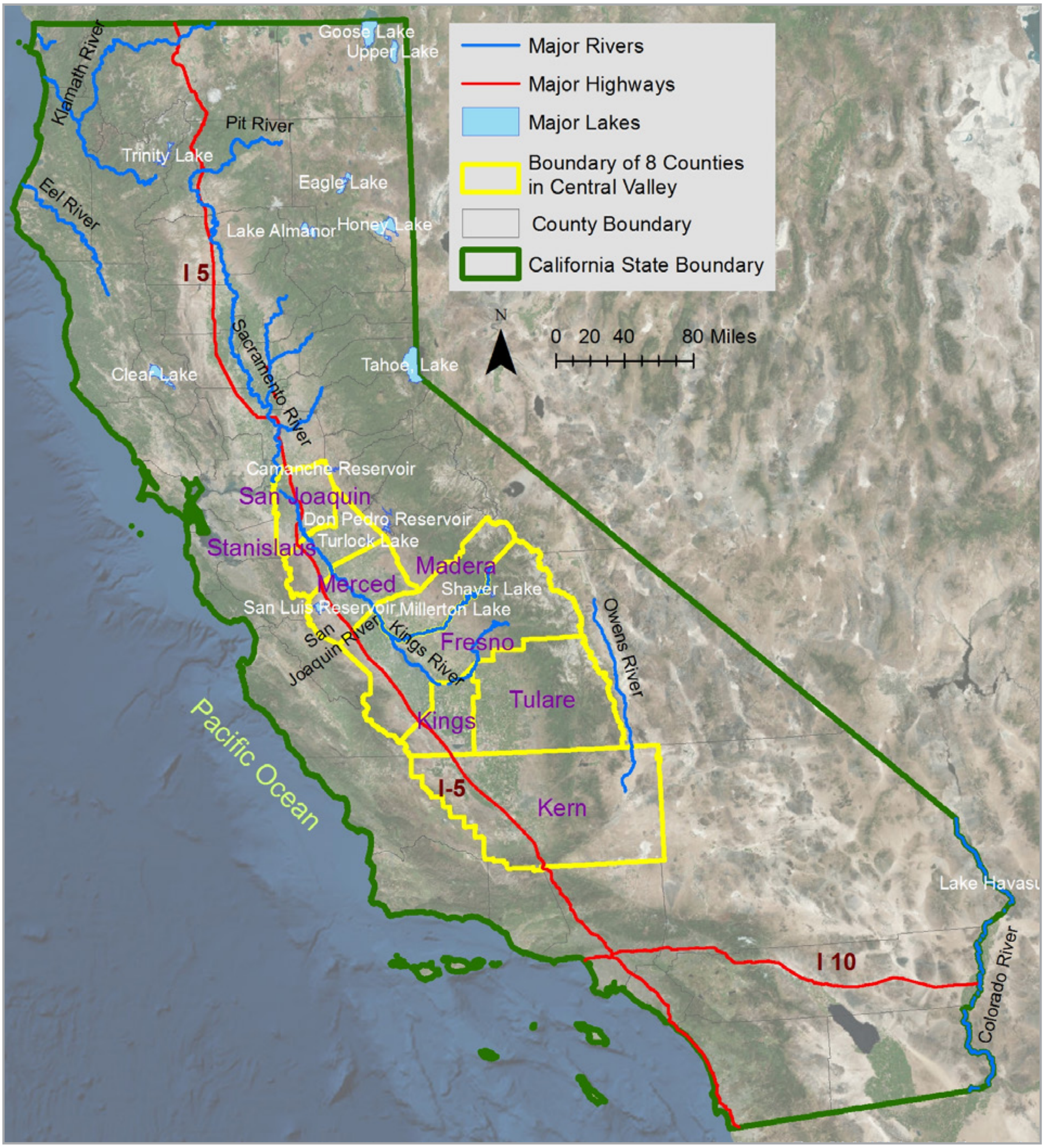
Setting the scene

This case study targets the San Joaquin Valley that forms the southern portion of the Central Valley's immense watershed (Figure 3.5.1) and is the geographic core of the agricultural industry in the State. The San Joaquin River flows down and through the San Joaquin Valley from the once-thick snowpacks of the Sierra Nevada Range. Due to its semi-desert environment, the San Joaquin Valley ("the Valley") uses the majority of its water for its agricultural industry: the impact of the drought has been harsh.

Scientific evidence

A range of scientific research has suggested a link between anthropogenic warming and an increase in the occurrence, strength, and length of droughts in California (IPCC, 2014; Ingram and Malamud-Roam, 2013; Yoon *et al.*, 2015; Griffin and Anchukaitis, 2014; Diffenbaugh *et al.,* 2015; Cook *et al.* 2014; Cook *et al.*, 2015). Extreme weather events such as floods and the

Figure 3.5.1 Yellow border indicates the 8 counties of the San Joaquin Valley that are the heart of agriculture in California



Dammed Rivers: If this map had been created early in the 20th century, in Tulare County would be a huge blue Tulare Lake, once the second largest freshwater lake in the US, fed by four rivers in the southern San Joaquin Valley. The waters of all four rivers have been dammed and diverted, mainly for agricultural use.

Source: Dr. Fayzul Pasha and Dr. Dilruba Yeasmin (California State University, Fresno)

current drought surpass the natural climate variability of the region (Ingram and Malamud-Roam, 2013; Yoon *et al.*, 2015).

Winter snow pack is a major contributor to California's water supply. On April 1, 2015, California's Department of Water Resources reported that no snow was to be found on the Phillips Station measuring plot, at 2,072 meters of altitude in the Sierra Nevada Range. The historical average depth of snow on that date for Phillips Station had been 1.69 meters. The Department of Water Resources (2015) noted the warming trend that has made California's winter of 2014-2015 the warmest in its recorded history. A team of scientists analyzing the risk of increasing severity and length of droughts in California confirmed that annual rainfall shortages were more than twice as likely to lead to drought if the year was also relatively warm (Diffenbaugh *et al.*, 2015). They concluded that anthropogenic warming has increased the likelihood of the dry warm years that create drought. Further, continued global warming presents the risk of a future regime where almost every single annual rainfall deficit, will coincide with increased temperatures. Their climate model simulations demonstrated that California's warming clearly increases when both human and natural forcings are included but do not increase when only natural forcings are included. They conclude that human forcing has caused the observed increase in probability of dry warm years (Diffenbaugh *et al.*, 2015). The potential scenario of a nearly 100 percent risk of dry warm years creating drought, especially extreme drought, escalates the risk of dangerous consequences for human systems, for ecosystems, and for the services that ecosystems provide.

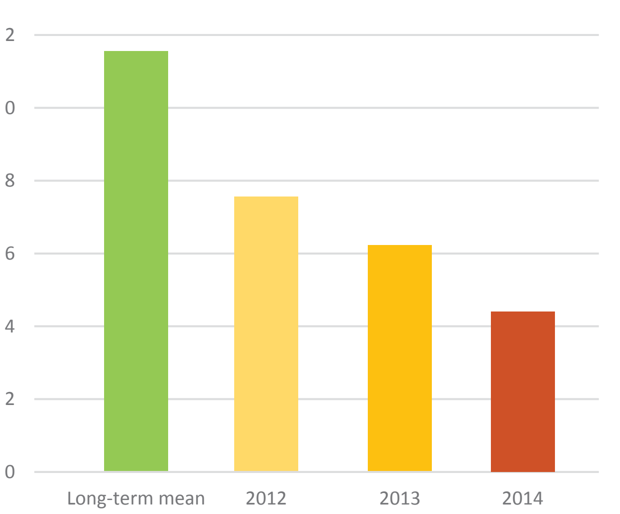
Another team of researchers demonstrated that the risk of mega-droughts is high for the US Southwest in the latter half of the 21st century. In 2014, the team found that increased greenhouse gas concentrations were primarily and consistently driving cross-model drying trends and the resulting increases in evapotranspiration would likely counterbalance any increases in rainfall (Cook *et al.*, 2014). In a follow-up study, the team considered the ongoing scientific uncertainties about anthropogenic influence on future climates within analyses of drought variability and within millennial-long historical and paleoclimate records. The scientists determined that increase in evapotranspiration is one of the dominant drivers of global drought trends. Their research indicates that under a business as usual emissions scenario, the risk of multi-decadal droughts between 2050 and 2099 in the US Southwest is more than 80 percent. The megadrought potentials were demonstrated in both high and moderate future emissions scenarios (Cook *et al.*, 2014; Cook *et al.*, 2015).

Cascading effects

The provisioning ecosystem services of stream flow and groundwater sustain agriculture in California, and they have been greatly affected by the drought. Mountain stream flow originating in the Sierra Nevada Range is augmented by rainfall and channelled into California's enormous system of man-made dams, reservoirs, aqueducts, pipelines, and tunnels. In a drought, the reduced inflow from snow melt and rainfall starts a cascade of effects in the Valley. Less snowpack results in less surface flow. That triggers increased dependency on groundwater extraction for domestic, agricultural, and industrial use. But less surface flow also reduces natural groundwater recharge. In the San Joaquin Valley, reduction of surface and groundwater availability is particularly significant because agriculture is so extensive and that agriculture depends on the ability to pump groundwater when needed. Scientists estimate that in the first 10 months of 2015, California farmers pumped over 7.5 kilometers^3 of water, and during the entire drought some depths to stressed aquifers sank over 30 meters (UCD 2015) (Figure 3.5.3).

Mining of the aquifer—extracting groundwater without putting anything back—has made the Valley the most severe case of land subsidence in the nation. New mapping technologies allowed researchers from NASA's Jet Propulsion Lab to map subsidence during the drought to resolutions of centimeters (Figure 3.5.4). The California Department of Water Resources completed

Figure 3.5.2 Historical Rainfall: 8 Counties of the San Joaquin Valley

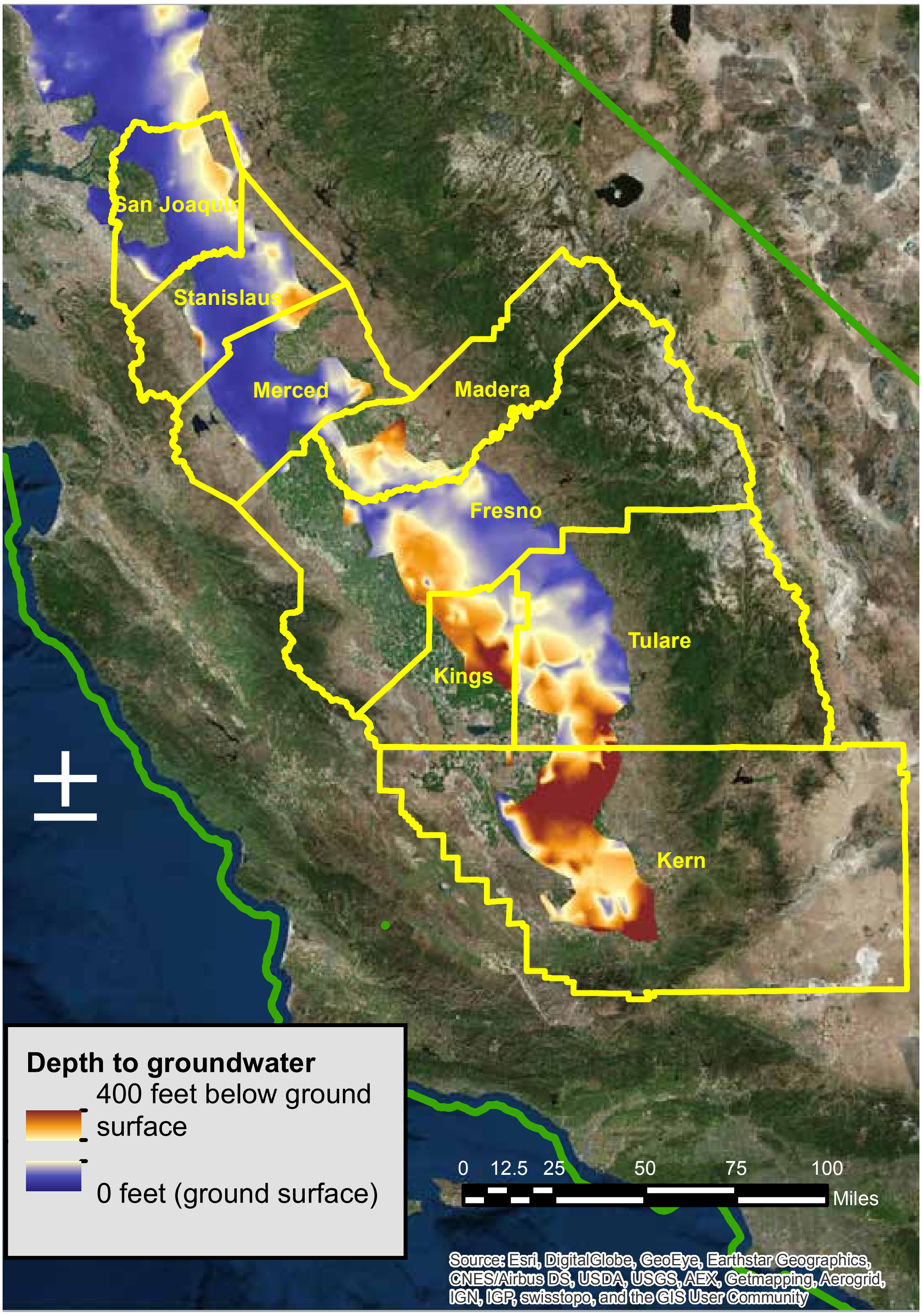


Source: Pasha (2015)

Dried up San Joaquin River: Diversions from California's vast systems of dams and canals can drain rivers. The San Joaquin River, pictured here, runs dry for miles.

Photo Credit: Deanna Lynn Wulff

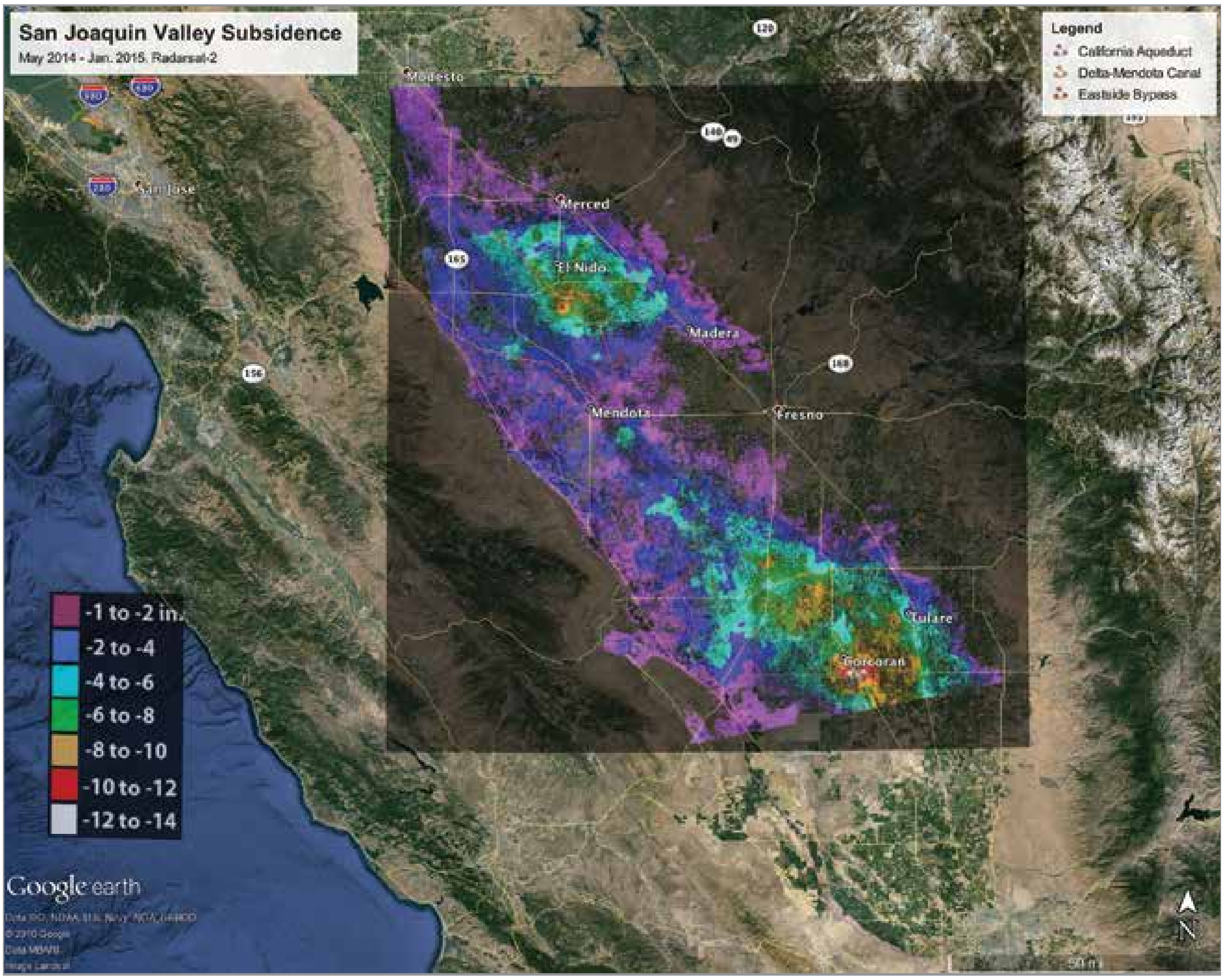
Figure 3.5.3 Depth to groundwater, spring 2014, in the eight counties of the San Joaquin Valley (outlined in yellow).



Source: David Drexler (Fresno State), based on California Department of Water Resources data from 2014

its own land survey along the California Aqueduct in San Joaquin Valley to discover over 70 miles of the aqueduct's path had subsided 0.38 meters in two years (NASA 2015). As the aquifer is depleted, rocks and soil compact and fall in on themselves, providing less solid support to the ground above and to any infrastructure built there. Finally, the subsoil can compact to such an extent that the storage capacity of an aquifer is permanently damaged: as is the provisioning ecosystem service the aquifer provides (USGS, 2015).

Figure 3.5.4 NASA's Jet Propulsion Laboratory map showing total subsidence in California's San Joaquin Valley for the period May 3, 2014 to Jan. 22, 2015.



Source: NASA's Jet Propulsion Laboratory, based on Canada's Radarsat-2 satellite (Canadian Space Agency/NASA /JPL-Caltech)

Two large subsidence bowls are evident, centered on Corcoran (lower left) and south of El Nido (upper center) (indicated by red) (NASA, August 2015).

Dr. Poland who investigated land subsidence in the San Joaquin Valley poses for a photograph showing the subsidence from 1925-1977 (USGS, 9 December 2015).

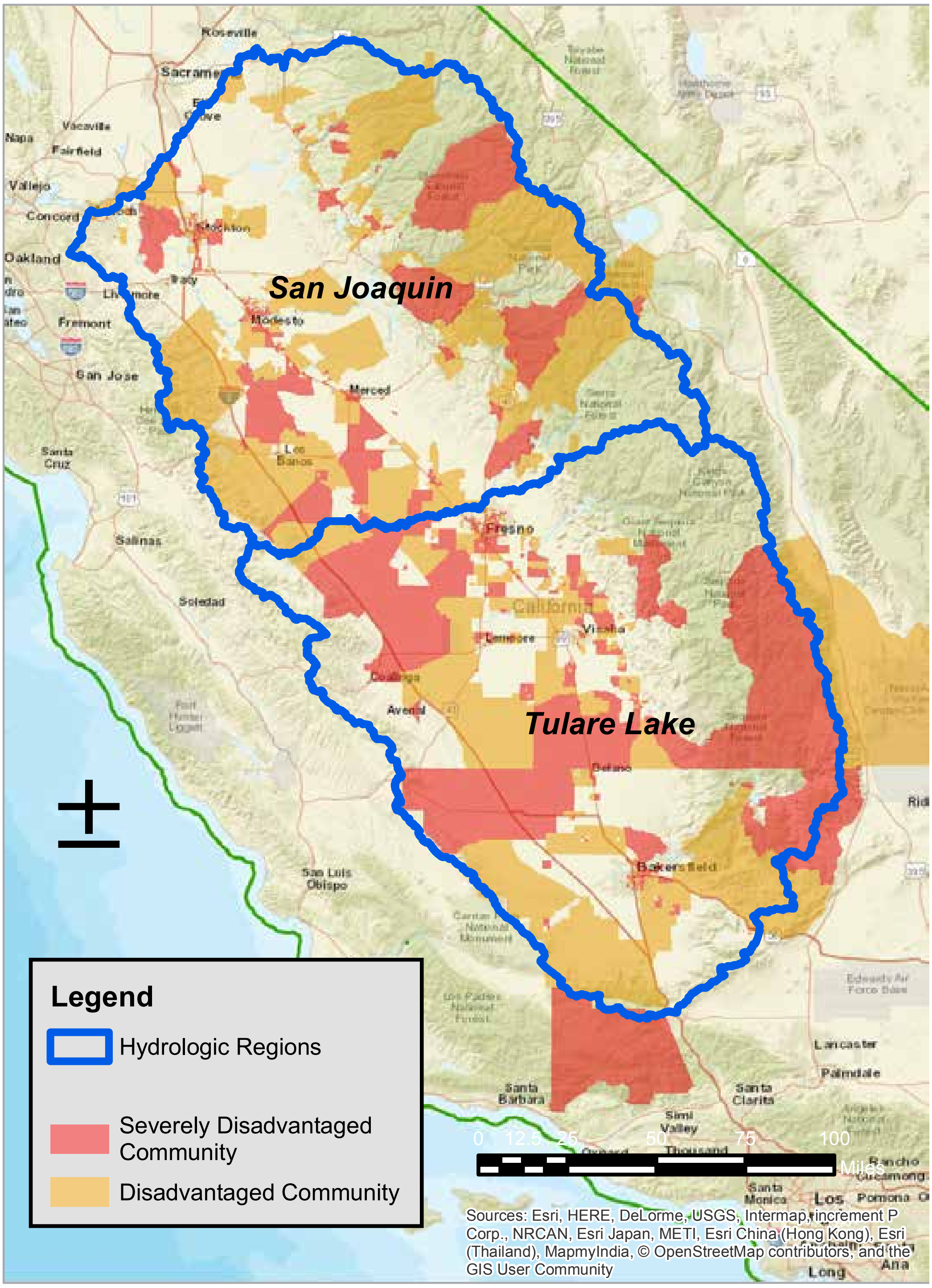
Photo Credit: http://water.usgs.gov/ogw/pubs/fs00165/ - Land Subsidence in the United States, USGS USGS Fact Sheet-165-00

The cascading effects on human systems continue. Agribusiness enterprises usually own the most powerful and deepest wells. The surrounding communities, often composed of farm laborers, have cheaper and shallower wells. These communities are frequently classified as economically disadvantaged, meaning their average median household income is less than 80 percent of the state's (Avalos, 2015; Harootunian *et al.*, 2015) (Figure 3.5.5). Sometimes these disadvantaged communities are unincorporated, so they are not connected, or have never been able to connect, to municipal water and sanitation services (Policy Link, 2013). As agribusiness mines the aquifer, its levels plummet, and shallower domestic wells run dry. This lack of potable water has its own cascade of effects, including a range of diseases. For example, researchers documented spikes in campylobacter diarrheal illness, a food borne disease (Sherchan, 2015). At the same time, insect borne diseases can increase, such as West Nile Virus because birds, host to the WNV, flock to urban centers with steady water supplies, and mosquitoes then transmit the disease from birds to humans (Sherchan, 2015). Finally, more air-borne particulates and other air pollutants can contribute to increased occurrence of coccidioidomycosis fungal lung disease, also known as Valley Fever (Sherchan, 2015; Harootunian *et al.,* 2015).

Policy response

A lack of any public reporting requirement and monitoring equipment only exacerbates the maladaptation of aquifer depletion in the San Joaquin Valley. In response to the disturbing data on the depletion of groundwater basins, the 2014 California legislature passed the Sustainable Groundwater Management Act (SGMA). It will take 25 years for the SGMA to have full effect: 2040 is the date set for nearly 200 Groundwater Sustainability Agencies to achieve their goals. However, the legislation is significant because it broke through a 160-year labyrinth of litigation over water rights. Water rights and property laws established in the early days of statehood, and grounded in precedents set long before, still influence policies in which generations of public, private, and civil society interests have invested. Some studies suggest that federal insurance policies set up decades ago may now be functioning as entrenched systemic barriers to adaptation efforts (Frisvold, 2015; Christian-Smith, 2014). Federal crop insurance and agricultural disaster assistance could be inhibiting incentives to change by providing generous payments to farmers despite the reluctance of some to adapt. During the drought, gross revenue actually increased for many of San Joaquin Valley's bigger farmers, who persist in mining the aquifer or other unsustainable

Figure 3.5.5 Economically Disadvantaged Communities ("DAC") in the San Joaquin Valley.



Source: David Drexler (Fresno State), based on California Department of Water Resources data from 2015

water practices. One reason for the revenue increase is crop substitution, when farmers switch to growing crops such as almonds that are water-intensive but high-profit under market scarcity conditions (Harootunian *et al.*, 2015; Frisvold, 2015; Christian-Smith, 2014).

At the same time, those in greatest need of public insurance–the farm laborers who are unemployed or underemployed during a drought–often cannot gain access to such services (Harootunian *et al.*, 2015). US Department of Labor statistics show that 80 percent of unauthorized farm labor live below the poverty line yet only 5 percent of them secured unemployment insurance (USDoL, 2015).

New California legislation--especially the SGMA—could be an important beginning. Much more needs to follow, including reform of practices and policies that reduce local incentives to adapt. The science team from NASA, Cornell, and Columbia (Cook *et al.*, 2015) predicted mega-droughts that will represent a fundamental and unprecedented climate shift from the past millennium, which means these mega-droughts are completely outside of the experience of both natural ecosystems and human systems in the region. Adaptation will be a challenge, one that will be compounded by corrosive and even reckless maladaptation (Cook *et al.*, 2015).

4. POLICY SOLUTIONS

As discussed previously, ecosystems provide services that sustain human societies: supporting nutrient cycling, soil formation, and primary production; providing food, freshwater, fibre, and fuel; regulating climate processes, flood cycles, disease resistance, and water purification; and maintaining cultural dimensions for aesthetic, spiritual, educational, and recreational purposes (MEA, 2005). Climate variability and change, experienced as both extreme weather and slow-onset processes, affect all four ecosystem-service types in different ways, as explored in the case studies in this report. The case studies illustrate how climate-related stressors and even specific weather events can influence the dependable functioning of ecosystem services, including primary productivity, food and freshwater supplies, flood cycles, climate regulation, soil stability, and disease control. This in turn has adverse effects on key elements of human society, disrupting facets of human well-being such as health and basic materials for good life.

All countries will require pathways that lead to more climate resilient development in the face of increasing intensity and frequency of weather extremes and of incremental but profound shifts in natural systems, like sea level rise and desertification, driven by climate change. However, the adverse effects of climate change are widely recognized as unevenly distributed across and within nations because of differing exposures, vulnerabilities, and coping capacities (IPCC, 2015). Thus, developing countries will need support to respond and to develop strategies that anticipate climate change impacts. Addressing loss and damage requires a range of approaches from those aimed at minimizing the impacts of climate change to those focused on helping human societies address and build resilience to the residual impacts of climate change using tools such as insurance and social protection measures.

At the 2015 21st UNFCCC Conference of Parties in Paris, 197 countries agreed that areas of international cooperation and facilitation to enhance understanding, action, and support regarding loss and damage include (UNFCCC, 2015):

- Early warning systems
- Emergency preparedness

Fishing in Bangladesh.

Photo Credit: Sonja Ayeb-Karlsson

- Slow onset events
- Events that may include irreversible or permanent loss and damage
- Comprehensive risk assessment and management
- Risk insurance facilities, climate risk pooling and other insurance solutions
- Non-economic losses
- Resilience of communities, livelihoods, and ecosystems

This chapter will provide an overview of how these policy areas could be tailored to address loss and damage to ecosystem services and how ecosystem services can play a role in avoiding, minimizing and addressing loss and damage. The starting point is recognizing the importance of ecosystem services for human well-being.

4.1 Assessing loss and damage to ecosystem services

Understanding the value of ecosystem services can help reframe the way that ecosystems and their relationship to human well-being are viewed. Such understanding enhances appreciation of ecosystems' critical role in adapting and building resilience to climate change impacts (Costanza *et al.*, 2014; Zommers *et al.*, 2014). Recent years have witnessed new focus on developing tools and methodologies to measure the value of ecosystem services. The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative established in 2007 to mainstream the values of biodiversity and ecosystem services into decision-making at all levels (UNEP, 2013). New data from TEEB allowed an update in 2011 of the estimated annual value of ecosystem services globally from US $33 trillion to 125 trillion (Costanza *et al.*, 2014).

The International Union for Conservation of Nature (IUCN) initiated a series of studies to assess the comparative utility of various adaptation approaches, including ecosystem-based adaptation (EbA) (Rizvi *et al.*, 2014; Baig *et al.*, 2016): (1) cost-benefit analysis; (2) cost-effective analysis; and (3) multi-criteria analysis. In many cases the assessments show that EbA yields more benefit than hard adaptation options such as the construction of dams, seawalls and other infrastructure (Baig *et al.*, 2016). However, monetary assessments do not capture the non-monetary benefits provided by ecosystem services (Zommers *et al.*, 2014).

There are some aspects of ecosystem services that are difficult to monetize, especially culture-relevant ecosystem services and those that operate at planetary-system scales. Monetizing the value of ecosystem services and the potential outcomes when they suffer loss and damage presents an enormous challenge. Therefore, the calamities that can result from such outcomes are often poorly reflected in estimates of loss and damage. It is important to understand the magnitude of loss and damage to ecosystem services–both what has been incurred in the past and what is expected in the future–to develop and implement approaches that adequately address these dangers and their cascading consequences throughout human societies.

4.2 Avoiding and reducing loss and damage

Ultimately, mitigation is the best way to avoid future loss and damage (UNFCCC 1992; UNEP, 2014). However, according to the IPCC's AR5 (2014) historical emissions have already led to an increase in global average temperature of 0.85° C of warming making enhancing adaptation efforts and other approaches to avoid loss and damage imperative.

4.2.1 Adaptation

The IPCC defines adaptation as, "[t]he process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (Agard *et al.*, 2014). The AR5 distinguishes between incremental adaptation where the central aim is to maintain the essence and integrity of a system or process and transformational adaptation that changes the fundamental attributes of a system in response to climate and its effects (Kates *et al.*, 2012). Adaptation can be reactive, as in actions that are implemented after the onset of climate impacts, or proactive, as in actions that are taken in anticipation of climate change impacts. The latter requires projections of future climate change impacts with some degree of accuracy. The IPCC's Special Report on Managing

Box 4.1.1 Collecting data on climate change impacts

Country-Level Impacts of Climate Change (CLICC), a new project run by UNEP, seeks to develop common metrics so that climate change impacts, including loss and damage, can be assessed and graded on the country level. In doing so a comparison between countries will be possible, which has been impossible so far without an agreed approach on a consistent presentation of the information. The aim is to use easily understandable information, such as dashboards. The project also aims at informing national mitigation and adaptation planning, and could become a tool in the delivery of the UNFCCC NDCs. More information can be found here: http://www.unep.org/provia/CLICCPROJECT/tabid/1060147/Default.aspx

the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) found that timely communication of risks is essential for implementation of effective adaptation and risk management (IPCC, 2012). However, decision makers cannot wait for complete information–since new details and interpretations will be emerging continuously. Instead, decision makers can develop protocols for implementing low-regrets adaptation options, appropriate for a range of future climate scenarios, when predicted events manifest in real-time (Rosenzweig and Solecki, 2015).

The case studies in Chapter 3 briefly highlighted a number of adaptation measures for responding to the impacts of climate change. In the Sahel and the Horn of Africa, where changes in rainfall patterns are affecting crop and livestock production, adaptation strategies include crop-livestock integration, soil fertility management, planting of drought-resistant crops, water-harvesting, livelihood diversification, and seasonal or permanent migration.

In India and Pakistan, building designs that ameliorate effects of high temperatures could be an appropriate measure to adapt to anticipated heat waves. Afternoon breaks for outdoor laborers should be encouraged, to avoid the health threats posed by working during the hottest time of the day. The floods in India and Pakistan triggered calls for hard-engineered interventions such as dams, diversion canals, and reservoirs. However, these measures often have drawbacks over the longer term as natural systems adjust to their construction. As well, installation and maintenance costs generally run much higher than soft adaptation options. When hard options have unintended consequences, they are difficult to remedy or remove. Some adaptation options adversely affect local communities. Social cohesion can deteriorate unless great care and consideration is taken of the expectations, interests, needs, and well-being of those affected.

Adaptation strategies implemented in response to the drought in California tend to be reactive rather than proactive. Land subsidence has created the need for the state to repair damaged infrastructure and rebuild roads and bridges, while farmers have had to regrade fields and repair damaged infrastructure as well. The California case study suggests the need for more transformative solutions, however, given that power inequities manifest in unequal water access with health repercussions for the most vulnerable.

Focus group discussion of adaptation options and early warning systems for climate related hazards in Burkina Faso

Photo Credit: Zinta Zommers

Further, current adaptation measures are clearly insufficient and further measures must be employed to avert loss and damage. In fact, the adaptation gap–the breach between the adaptation options that are optimal and appropriate and the options that are currently implemented–is widening (UNEP, 2014). In all of the contexts profiled in the case studies, community based adaptation (CBA) has a potential role to play to reduce vulnerability and build resilience to future and continuing climate change.

4.2.2 Ecosystem-based approaches

Ecosystem-based approaches to adaptation integrate climate change concerns with sustainable resource management by conserving and enhancing ecosystems enhance adaptation (Nauman *et al.*, 2011). Reducing climate change impacts on ecosystems may buffer or minimize loss and damage to human systems (Zommers *et al.*, 2014). For example, research in Bangladesh has shown that the conservation of mangroves can both provide livelihood opportunities and protect against loss and damage from cyclones and storm surges (Shamsuddoha *et al.*, 2013b). In recognition of this the Government of Bangladesh has initiated a community afforestation and reforestation project (BCCRF, 2013.). EbA can be more cost effective than hard-engineered interventions such as infrastructure installations, more easily accessed by the poor as an adaptation strategy, and can enhance both livelihoods and human well-being (Rao *et al.*, 2013, Cutter *et al.*, 2012). Research has shown that EbA is most effective when designed as people centred with a strong participatory element (Reid, 2016). As well, EbA strategies can themselves adapt to changes in the climate and to adjustments in natural systems (Jones *et al.*, 2012).

The case studies in this report show that EbA has a role to play in avoiding loss and damage. The Pakistan case study suggested that EbA could reduce loss and damage from flooding through strategies such as re-vegetating catchments, restoring and creating wetlands, and preserving floodplains for agriculture and grazing. Building greenways could also provide corridors to support the movement of people and wildlife as the climate changes (Baig *et al.*, 2015). In fact a 7,775-km long green belt, known as the Great Green Wall of the Sahara and the Sahel Initiative, is underway to reach from Dakar to Djibouti (Dampha, 2013; GGWSSI, 2013; UNCCD, 2016). The initiative consists of many sub-initiatives supporting capacity building and ecosystem rehabilitation projects implemented by individual countries with support from development partners (GGWSSI, 2013).

The case studies on heatwaves in India and Europe drew attention to the importance of the role of ecosystems in buffering the effects of heat waves. Urban areas tend to be hotter and thus urban planning should include landscape plans to increase green open spaces (Wilhelmi *et al.*, 2012). Similarly, the India case study proposed planting trees to provide shade and green space and reduce urban heat stress. Since the 2003 European heat wave, limited proactive and reactive protocols have been put in place including warning systems, evacuation plans, and shelter designations. However continuing heat wave vulnerabilities emerge every few years, challenging assumptions that developed countries can claim advanced status in preparing for expected changes in climate (Kovats and Ebi, 2006; Lass *et al.*, 2013).

The case study of typhoon Haiyan highlighted long spans of coastal zone were devastated by strong winds. EbA management, including integrated coastal zone approaches, will help reduce and minimize loss and damage from future extreme weather events. Though preparing for events of magnitudes similar to Haiyan's will be challenging, EbA management will help the Philippines continue to recover from losses and damages to ecosystem services incurred by Haiyan.

The California drought is forcing communities, farms, and industry to increase use of aquifers as sources of water. Managing groundwater supplies to increase re-charge where possible could play a key role in the response to the drought. Future attention to design for surface water retention and recharge processes will be necessary for recovery of groundwater resources (Pahl *et al.*, 2013; Singh *et al.*, 2014). Participation of the communities that use ecosystem services and the integration of local and indigenous knowledge in EbA management are

Box 1.2.1 Ecosystem-based adaptation

Ecosystem-based adaptation (EBA) is defined as, "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels" (UNEP, 2012). EBA is premised on the fact that well-managed and diverse ecosystems can play an important role in adapting to climate change (MA, 2005; Reid et al., 2009). Some of the principles of EBA include promoting resilient ecosystems, maintaining ecosystem services, supporting sectoral adaptation, reducing risks and disasters, complementing infrastructure, and avoiding maladaptation. For example, mangroves and coral reefs can provide protection against storm surges, wetlands can act as reservoirs for flood waters, and erosion and landslides can be reduced with well-vegetated hillsides (Jones et al., 2012; Reid, 2016). Re-vegetating hillsides and slopes with grasses, bushes, and/or trees can also reduce erosion, landslides, and flooding and help retain soil moisture (UNFCCC, 2012).

essential to increasing shared ownership of ecosystem management responsibility (Biggs *et al.*, 2012; and Carabine *et al.*, 2014).

4.2.3 Community-based adaptation

Community-based adaptation (CBA) is a bottom-up approach to tackle climate change impacts; and is becoming increasingly popular for operationalizing local inclusiveness (Ayers, 2011). That said, CBA focuses on the priorities, needs, knowledge, and capacities of communities; and empowers them to plan and cope with immediate climate variability and long-term climate change (Reid *et al.*, 2009; Ensor and Berger, 2010). In practice CBA may resemble typical development activities; however, the difference is that CBA factors in the potential impact of climate change on livelihoods and vulnerability to disasters, using both local and scientific knowledge surrounding climate change (Reid *et al.*, 2009). In all of the contexts covered by the case studies CBA could be integrated with EbA to reduce vulnerability to future climate change impacts, averting or reducing future loss and damage. This is particularly important in communities that also face development challenges. The starting point for CBA is establishing an understanding of the needs of households and communities and then engaging them in a process to design adaptation strategies. Combining this with an understanding the contribution of ecosystem services to human well-being and their role in minimizing and averting loss and damage will ensure that adaptation more effectively reduces vulnerability to climate change.

Climate change is only one of a number of problems people face. As outlined in the case studies, a variety of factors, unrelated to climate, contribute to loss and damage to ecosystems or human systems (Reid *et al.*, 2009). At the local level, climate change concerns often merge with others to the point at which they cannot be disentangled. If a community is vulnerable because of development challenges and environmental, economic, or political marginalization, additional climate-related stressors will likely result in severe loss and damage. One of the main benefits of CBA is that it represents an opportunity to holistically understand how development and climate change concerns merge at the local level (Forsyth, 2013). It achieves this by adopting a community-led approach, addressing climate change vulnerability at the local level in its specific context of impacts and adaptive capacity (Ayers and Forsyth, 2009). In doing so there is greater potential for interventions to be more relevant to community needs and take into account local drivers of vulnerability

Discussion of climate change adaptation needs of disabled community members in Nairobi, Kenya.

Photo Credit: Zinta Zommers

(Forsyth, 2013). However, CBA does not only involve communities, it actively seeks to accommodate and build upon participatory processes with sub-district level governments, local stakeholders, and development and disaster risk-reduction practitioners (Huq and Reid, 2007; Reid *et al.*, 2009).

Advocates of CBA say excellent progress has been made in building local resilience and reducing vulnerability rather than assessing only physical climate risks (Ayers and Forsyth, 2009). While CBA is an evolving approach there are areas of concern. There is an underlying risk of local elite capture as is the case with all forms of localism (Kothari and Cooke, 2001; Mohan and Stokke, 2000). Additionally, sufficiently accurate local-level projections of climate change impacts are often unavailable, inhibiting its ability to reduce vulnerability to future climate change impacts (Forsyth, 2013). However, this is arguably not a problem restricted to CBA but applies to all efforts to reduce local-level vulnerability to climate change. It is also argued that CBA inadequately incorporates environmental concerns, and that there is a need to move beyond the static perception of ecosystem towards a fuller understanding of ecological complexity and interdependence (Reid, 2014). This is especially true when the changing climate is not static at all and will continue to deliver new extremes and unanticipated conditions for the next millennia at least (Solomon *et al.*, 2009).

4.2.4 Livelihood Diversification

Another important adaptation strategy is livelihood diversification. Where loss of ecosystem services impairs agricultural production, such as in the Sahel and the Horn of Africa, farmers can implement incremental adaptation measures to maintain their livelihoods, such as altering agricultural practices and improving access to markets, or they can transform their circumstances by diversifying their income. Diversifying livelihoods to be less dependent on agriculture or other climate threatened sources can both decrease risk and increase well-being (Cutter *et al.*, 2012). Livelihood diversification efforts need to consider the long-term implications of continually changing climate on ecosystem services. For example, re-training farmers as fishers is not a long-term livelihood diversification strategy if fish stocks are projected to decrease due to climate change impacts and other environmental pressures (Nishat *et al.*, 2013b). As with other adaptation options, communities, especially those whose livelihoods are most often affected, need to be actively engaged in the development of livelihood diversification strategies.

Livelihood diversification can also be an important strategy to introduce non-agricultural livelihood strategies like handicrafts and other ways of creating value for the benefit of local communities. This can be particularly relevant in situations where forest and land tenure is contentious or when community members are leasing the land they work. Tenure rights have important repercussions on community well-being for a number of reasons, the most obvious being that tenure is often used collaterally to access credit, financial support, or certain government programmes. To address these inequalities more transformational adaptation strategies may be needed. In the meantime livelihood diversification programs, such as providing training in sewing and handicraft as the Bangladesh Rural Advancement Committee is doing, could provide an alternative livelihood for the most vulnerable such as women living in extreme poverty (Nishat *et al.*, 2013b).

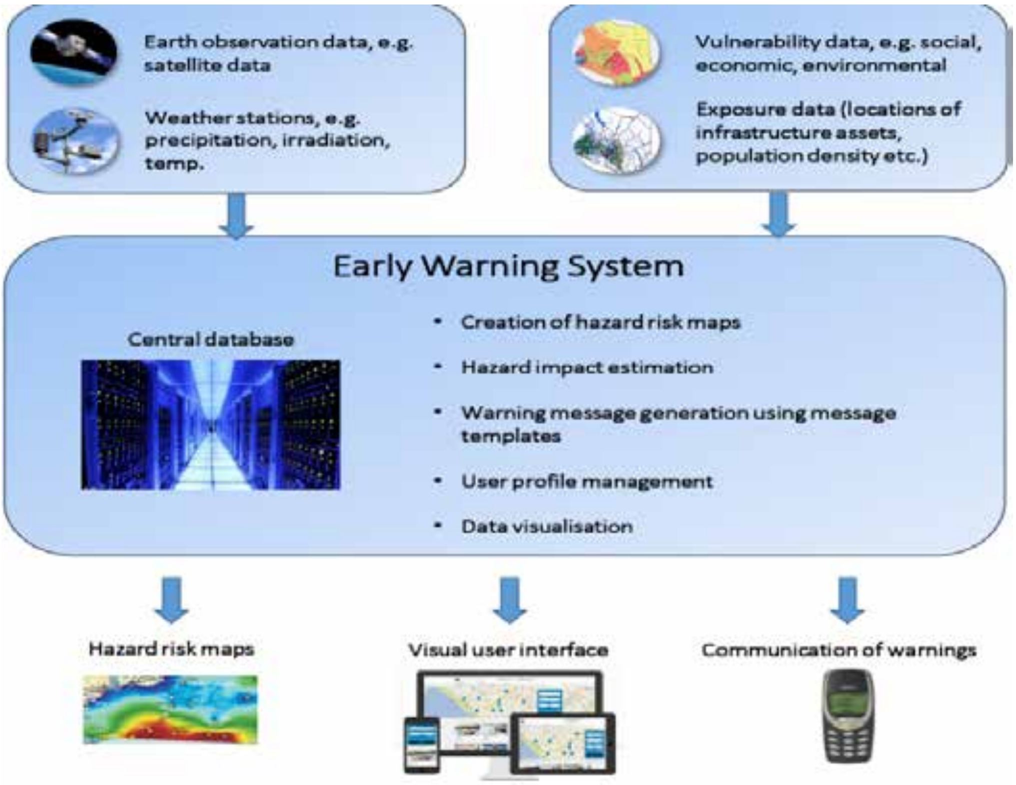
4.3 Risk reduction

Risk reduction measures are implemented before the advent of a weather event or climatic process to avert loss and damage and can be structural or non-structural. A range of risk reduction strategies will be needed, and indeed are already being implemented, in countries that are hit frequently by extreme weather events (UNFCCC, 2012). It can be difficult to distinguish risk reduction from adaptation on the ground. In fact, in the last decade calls for synergizing adaptation and risk reduction agendas have been increasing (Schipper and Pelling, 2006; Thomalla *et al.*, 2006; Schipper, 2009; Birkmann and von Teichman, 2010). Research on how loss and damage is being addressed in Bangladesh highlighted the need for better collaboration and communication between line ministries and other actors working on adaptation and disaster risk reduction, noting that the two communities could learn a lot from one another (Shamsuddoha *et al.*, 2013a). However, though there are similarities between the two, risk reduction tends to focus on reducing the risk of loss and damage from extreme events, specifically.

4.3.1 Early warning early action systems and forecast-based financing

One of the most well-known tools for reducing the risk of extreme weather events is early warning systems. Early warning systems have an important role to play in reducing loss and damage to ecosystem services and, importantly, in preventing the loss of lives. However, how and what early warnings communicate is important. Information about impending hazards needs to be accompanied by information about the risk posed by that hazard as well as the action that needs to be taken to reduce the risk (Cutter *et al.*, 2012). Early warning systems should also employ effective means of communication such as radios, megaphones, or mobile phones and should also be accompanied by awareness-raising activities to ensure the poor and most vulnerable, in particular, understand the risks and actions that can be taken to avoid losses and damages by responding to

Figure 4.3.1 Diagram of an early warning system.



Source: UNEP 2015

early warning systems (Cutter *et al.*, 2012; Shamsuddoha, 2013b).

One of the challenges in early warning is insuring early action to avoid loss and damage. Forecast-based finance (FbF) is an innovative funding mechanism that releases funds during the window of opportunity between a science-based early warning and the potential disaster that could follow (Red Cross/Red Crescent Centre, 2015). Taking advantage of this opportunity could avert or at the very least minimize a disaster through short-term to medium-term preparedness actions implemented before a possible disaster. Examples include distributing mosquito nets before the onset of heavy rains or positioning relief teams before roads close or wash out (Coughlan de Perez *et al.*, 2015). FbF uses forecasts issued at different lead times, from days to months, before the potential disaster manifests. Historically, this period of opportunity has rarely been exploited, with an estimated 88 percent of humanitarian financing disbursed after a disaster has already begun (Kellet and Caravani, 2013). However, given that the magnitude of extreme weather events is projected to increase and the gap between humanitarian aid and the needs on the ground is widening, there is a need to take advantage of this window. Humanitarian agencies can get information about when and where extreme-weather events like storms, floods, and droughts are expected. Many humanitarian actions could be implemented in the window between a forecast and a disaster, given the proper financing. This would reduce costs and needs after the event.

Funding used in FbF would be sourced from an already established fund with financial procedures in place that would allow for the rapid disbursement of financing based on predefined thresholds (Coughlan de Perez *et al.*, 2015). Since 2012, the World Food Programme and German Red Cross established several pilot projects in Asia, Latin America, and Africa.

Standard operating procedures for FbF include a scientific threshold based on one or several forecast models and decide on the moment when the system wants to act and with which kind of actions. Since the system is standardized, disaster managers will not be blamed if the disaster does not materialize. Occasionally acting in vain is accepted, knowing that the costs are still significantly greater if the system is not taking early actions in a situation of increasing risk.

Similar to the fundamental culture change that is required for donors and decision makers to take action based on a forecast, there is a culture change required in the way that thresholds in forecasts are perceived by the various stakeholders. This will likely include the National

The training workshop and field exercise on emergency shelter organized by the Peruvian Red Cross branch in the Lambayeque capital, Chiclayo on 24–26 February. The region is a centre of the German-supported 'Forecast-based Financing' programme in the country, currently focusing on El Niño impacts.

Photo credit: Peruvian Red Cross

Meteorological and Hydrological Services, the national and sub-national government departments responsible for disaster management and NGO and humanitarian groups, such as the Red Cross/Red Crescent.

4.3.2 Community-based risk reduction

In recent years there has been increasing focus on community-based risk reduction to increase participation of the most vulnerable in the planning, development, and implementation of risk reduction strategies and plans and to ensure that their needs are met. For instance, after the 2010 floods in Pakistan, ActionAid trained 1000 women to lead efforts to engage with local governments in designing risk reduction plans to ensure the plans integrate the needs of women and girls (Action Aid, 2014).

Questions have been raised about who represents a community and how to ensure fair distribution of resources when a community is used as an entry point for adaptation, risk reduction and development interventions has been contested. According to the 2014 World Disaster Report that focused on culture and risk, there are three major challenges when intervening at community level. The first considers assumptions that communities are uniform, homogenous entities without internal conflicts or divisions. The second examines power systems at the local level and focuses on the elite capture of development resources. The third argues that because of internal divisions and power relations, participation is almost always likely to be distorted in favour of some people or groups (IFRC, 2014).

For example, land tenure has a significant impact on vulnerability and landowners can exert influence over risk reduction efforts. That said, through local level, community-based interventions these inequalities can be acknowledged and attempts can be made to address the root causes of vulnerability. Understanding why people are vulnerable and how social norms and cultural beliefs influence perceptions of risk and actions to address risk needs to be better understood (IFRC, 2014).

4.4 Addressing residual losses and damages to ecosystem services

Despite adaptation efforts and risk reduction plans, climate change will produce some loss and damage (Dow *et al.*, 2013; Preston *et al.*, 2013; Klein *et al.*, 2014). Measures are needed to address climate change impacts that cannot be, or are not, averted. These measures can be used to address residual losses and damages to ecosystem services, while recognizing that there are many overlaps among the objectives of development, disaster prevention, adaptation, and humanitarian response programmes. Ultimately, comprehensive risk management frameworks that include a range of approaches will be needed in all these efforts.

4.4.1 Risk transfer

Insurance reduces the catastrophic impact of some extreme events by spreading losses among people, over large areas, and across time. Insurance tools motivate risk reduction and play a role in avoiding loss and damage. They can also help bridge financial gaps when losses occur (Warner *et al.* 2012). Insurance is used to address impacts associated with extreme weather events but is not generally feasible for slowly developing and foreseeable events or processes that happen with high certainty under different climate change scenarios (IPCC, 2012). Insurance is also relevant to loss and damage in ecosystem services, particularly in the context of agricultural production.

Insurance arrangements can alleviate the damage that extreme events cause to lives and livelihoods, but they require an enabling environment. Experience shows that insurance is best applied in conjunction within a comprehensive risk management framework that includes risk assessment, early warning, risk reduction, risk transfer, and rehabilitation (Warner *et al.,* 2010; Warner *et al.*, 2013; Yuzva *et al.*, 2014). Even for weather-related events, insurance is not optimal for large events that occur with very high frequency, such as recurrent disastrous flooding. Resilience building and the prevention of loss and damage in such instances can be cost effective ways to address these risks.

A framework for detecting magnitude, location, and vulnerability to climate risks

Insurance does not prevent or reduce the likelihood of direct damage and fatalities from extreme weather events. It is not always the most cost-effective or affordable approach and it could become irrelevant as more circumstances are designated uninsurable with increasing frequency and magnitude of extreme weather events (Bower *et al.*, 2007). These limitations have led to one of the most important insights for how insurance can contribute to addressing the adverse effects of climate change: It can be embedded in a comprehensive climate risk management system that uses risk assessments, risk reduction, and prearranged procedures for distributing insurance payouts. A combination of measures that includes insurance can reduce maladaptation, as well as reduce immediate losses and long-term development setbacks from adverse climate change impacts. Risk assessments are a core function of insurance approaches as they increase understanding of the potential hazards, exposure, and vulnerability. They can also raise awareness and reveal new options for managing the risks (Warner and Speigel, 2009). Insurance prerequisites—including hazard maps and risk information; appropriate regulation, building codes, zoning, and consumer protection; and financial adequacy—can catalyze anticipation and management of adverse climate impacts.

A major drawback is that insurance is not available or affordable in many developing countries, particularly for low-income populations with few assets and high exposure. Even in developed countries, the poor cannot afford insurance. For example, as discussed in the case study, many of those most affected by the European heat wave were elderly with very little disposable income. Climate-related disasters often affect whole communities or regions. To realize potential coverage for the vulnerable insurers must have sufficient capital and reinsurance to meet large claims at one time.

Multi-country risk insurance pools provide risk management support to their members. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) was established following major hurricane devastation in the Caribbean. It addresses governments' need for risk transfer options as well as the lack of affordable insurance for citizens. The CCRIF was designed to provide quick insurance payouts that are intended to ease liquidity constraints in the aftermath of hurricanes or earthquakes. It is now a separate loan portfolio company, allowing it to expand membership to Central America (CCRIF SPC, 2015). The Africa Risk Capacity (ARC) programme´s model arose from a need to speed the provision of humanitarian assistance related to drought. ARC includes a regional forecasting model, contingency planning that outline how insurance payouts will be distributed to alleviate food shortages, the insurance pool, rating services, and a new Extreme Climate Facility that facilitates direct access to climate adaptation finance for eligible African governments (ARC, 2014; ARC, 2015).

In coming years, as the policy landscape for addressing climate change evolves, three actions will help insurance contribute effectively to managing adverse effects of climate change (Warner and Spiegel, 2009).

- Realizing technical and institutional advances that enable diversification and sharing of risks from extreme weather events;
- Lowering the costs of managing these risks; and
- Ensuring more timely and targeted delivery of support when extreme events strike.

Coordinating these three actions when implementing strategies and programs will increase effectiveness and the efficiency of the insurance programs, especially in addressing the challenges of loss and damage (Warner *et al.*, 2012). The Paris Agreement established a clearinghouse for risk transfer under the Warsaw International Mechanism for loss and damage (UNFCCC, 2016). Work to begin fulfilling these three tasks could be taken up by this emerging body.

4.4.2 Risk retention

Risk retention is defined as self-insuring by building resilience to the impacts of climate change through tools such as social protection or by establishing financial reserves to cushion the blow when climate change impacts occur (UNFCCC, 2012). Both have a role to play in addressing loss and damage from ecosystem services. Social protection measures can help societies bounce back from the onset of unexpected, severe weather events and build resilience to slow onset climatic processes. Where events are unexpected, financial reserves can help repair the damage and help societies recover from losses. Governments at various levels require a thorough understanding of the range of future climate scenarios, of who is vulnerable, and of where the vulnerable are located to implement risk retention policies that effectively reduce vulnerability and build resilience. There is also a range of risk retention strategies that households can adopt to build resilience and cushion the blow when losses and damages to ecosystem services are incurred. One of these is microfinance, though there are a number of challenges to ensuring that effectiveness (UNFCCC, 2012).

National and regional protection programmes

Social protection programmes, including social safety nets, can play a significant role in preventing the impacts of climate change from impeding development progress (UNFCCC, 2012). Several countries have already implemented social protection programmes that have been integrated into the national climate change strategies. The Ethiopian case is often highlighted as a model for other countries. Each year the Productive Safety Net Programme (PSNP) provides up to six months of food and cash transfers to chronically food-insecure households in exchange for the provision of labour of members of the household on public works projects (WFP, 2012). The PSNP served as the foundation for part of the Horn of Africa Risk Transfer for Adaptation programme, the predecessor of the R4 Resilience Initiative (World Bank, 2013). The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) and its environmental benefits program has found that households need guaranteed, predictable, and inclusive wages and durable assets that respond to livelihood needs with flexibility within changing climate contexts With the rural poor as its target group, MGNREGA provides 100 days of employment in exchange for labour on public works projects. Wages are based on the consumer price index to ensure that rural households can continue to meet their basic needs with fluctuating prices (MGNREGA, 2005; Steinbach *et al.*, 2016).

For social protection programmes to be dependable and effective, it is important that measures are in place to ensure that the most vulnerable are targeted and reached and to accurately determine when individuals or households have graduated from programmes. These measures also require significant and sustained finance, a requirement that is difficult or impossible for some countries, especially least developed countries (UNFCCC, 2012). In recognition of this, the World Bank established the Sahel Adaptive Social Protection Program Trust Fund in 2015 to enhance access to adaptive social protection systems for the poor and vulnerable in Burkina Faso, Chad, Mali, Mauritania, Niger and Senegal (World Bank, 2015). Adaptive social protection is a framework developed by the World Bank to integrate social protection with responses to climate change and ensure these measures

Box 4.2.1 The R4 Resilience Initiative

The R4 Resilience initiative is a partnership between the UN World Food Programme (WFP) and Oxfam America that was initiated in 2011, building on the success of the Horn of Africa Risk Transfer for Adaptation. The R4 Resilience Initiative has four components: (1) risk reduction through improved resource management and climate services; (2) risk transfer through micro-insurance; (3) prudent risk taking through livelihood diversification and microcredit, and (4) creating risk reserves through savings. R4 has been implemented in Ethiopia, Senegal, Malawi, and Zambia. Premiums for the insurance are paid either in cash or in exchange for labour in community risk reduction projects. A total of 27,000 farmers participate in R4 in Ethiopia, 6,000 in Senegal, and nearly 1,000 in Malawi and Zambia (WFP and Oxfam America, 2015).

reach those most vulnerable to the impacts of climate change. Most of the funding for the project will be provided to countries in the form of grants to support pilots and to advance learning on innovative policies and programmes. The aim is to support the development and implementation of institutions and procedures that will lead to the establishment of adaptive social protection systems in these six countries (World Bank 2015).

National contingency funds

Despite planning, preparedness, and risk management schemes, some climate-related loss and damage is inevitable. Responding to extreme events like Typhoon Haiyan or the 2010 Pakistan floods can divert significant resources from national budgets and impede development. Establishing contingency or reserve funds, set apart from day-to-day national budgets, can help ensure that finance is available for immediate relief in the wake of an extreme event. Some governments have already established such funds with their own resources. In 1996, the Government of Mexico established the Fund for Natural Disasters (FONDEN). At the beginning of each fiscal year the Mexican government dedicates at least 0.4 percent of the national budget to the FONDEN Program for Reconstruction, the FOPREDEN Program for Prevention, and the Agricultural Fund for National Disasters (World Bank, 2012). Through the FONDEN Program for Reconstruction, funds are available in the wake of a disaster to support the rapid reconstruction of federal and state infrastructure, low income housing, and the rehabilitation of the natural environment (GFDRR, 2013).

When properly managed, contingency funds quickly disperse resources to support rapid response, rehabilitation, and recovery efforts. However, these funds can be difficult to establish and maintain. Support from international donors could address these difficulties, especially those experienced by least developed countries that are also most vulnerable to climate-related loss and damage to ecosystem services. With assistance from development partners, Bangladesh has established the Bangladesh Climate Change Resilience Fund to implement the Bangladesh Climate Change Strategy and Action Plan. The fund supports adaptation and mitigation projects, one of which was a community afforestation and reforestation project in coastal Bangladesh to provide protection against cyclones and diversify the livelihoods of those who have been dependent on the forests (BCCRF, 2015)

Woman and child in Bangladesh.

Source: Sonja Ayeb-Karlsson

Local level
Households in developing countries are often forced to make difficult choices when faced with loss and damage. In some cases erosive coping strategies, such as selling livestock or removing children from school, are adopted that have long-term development consequences. There are, however, strategies that can be taken at the local level by households to provide reserves and cushion the blow when losses and damages to ecosystem services are not avoided (Warner and van der Geest, 2013).

Microfinance
Microfinance generally refers to the provision of small-scale financial services to low-income and otherwise disadvantaged groups who are not served by formal financial institutions. Microfinance institutions refer to any institution offering these financial services, most notably non-governmental organisations. However, the modern microfinance sector is so diverse that some banks offer microfinance products.

In theory microfinance catalyzes the ability of households to increase income and assets and to improve strategies for managing cash, resources, and risk (de Aghion and Morduch, 2005). In practice much of this theoretical promise has failed to be demonstrated by empirical evidence. (Chowdhury, 2009; Collins *et al.*, 2009; Stewart *et al.*, 2010; Duvendack and Palmer-Jones, 2011; Bannerjee *et al.*, 2015)

Despite these limitations, interest continues in the role that microfinance may have as part of everyday household efforts to manage livelihood risk. More focused studies show that microfinance can help households to cope with risk, in particular by smoothing consumption. Additionally, it may help households self-insure by allowing livelihood diversification (Heltberg *et al.*, 2009; Hammill *et al.*, 2008).

Understanding of the potential role for financial arrangements in managing risk remains largely theoretical (Fenton *et al.*, 2015). Some research suggests that microfinance may frustrate risk management, a circumstance that can increase vulnerability by restricting coping mechanisms during livelihood shocks (Morduch and Sharma, 2002). Recent problems with over-indebtedness have also been cited (Taylor, 2012).

There is some interest in the role that microfinance may have as a component of wider climate change programmes and projects. Successful microfinance institutions offer a reliable route through which adaptation finance can be channelled to low-income and otherwise disadvantaged groups (Agrawala and Carraro, 2010; Fenton *et al.*, 2015).

One example of microfinance being embedded into climate change projects is the Microfinance for Ecosystem-based Adaptation project (UNEP-ROLAC/FS-UNEP Centre, 2014). The programme represents an example of green microfinance that deliberately influences households to reduce their vulnerability and contribution to environmental stresses (Huybrechs *et al.*, 2015). This programme works with microfinance institutions to tailor services for rural populations that are vulnerable to climate change. Additionally, customized capacity building is provided to microfinance institutions to help them incorporate climate change concerns. Furthermore, it creates partnerships with key local practitioners to improve climate change resilience with a focus on ecosystem-based adaptation (UNEP-ROLAC/FS-UNEP Centre, 2014).

4.4.3 Recovery, reconstruction and rehabilitation

The case study of typhoon Haiyan highlighted the importance of humanitarian assistance followed by recovery, rehabilitation, and rebuilding. After events of this magnitude, timely delivery of international aid is crucial to ensuring that recovery can proceed quickly to limit the loss of life. If national contingency funds exist, then recovery and reconstruction can proceed more quickly.

Over the past decade, significant research and on-the-ground experience determined what helps communities recover and rebuild after significant losses and damages are incurred from extreme events. Since the Indian Ocean tsunami in late 2004, reconstruction efforts have increasingly focused on building back better (Fan, 2013). The aim of building back better is to make infrastructure and livelihoods more resilient rather than restoring the same conditions that existed prior to the onset of an event, or worse conditions as often happens after disasters in poor communities (UNOCHA, 2014). Building back better could entail strengthening regulations such as building codes and ensuring that the poorest and most vulnerable have access to safe housing (Martinez-Solimán, 2015). Some humanitarian agencies involved in the rebuilding efforts in Tacloban, the area most affected by typhoon Haiyan, are aiming to integrate the concepts of build back better into reconstruction efforts (Plan, 2014; UNOCHA, 2014; World Vision, 2014; UNISDR, 2015; UNICEF, 2015).

In the wake of extreme events, focus tends to be on rebuilding infrastructure and re-establishing the provision of services; but in some cases rehabilitating livelihoods is equally, if not more, important. Where the provisioning ecosystem services of agriculture are impaired by extreme events, schemes are needed

House damaged by flooding in Bangladesh.

Source: Sonja Ayeb-Karlsson

that provide seeds and planting materials and that rehabilitate land (Cutter *et al.*, 2012). In the case of slow onset processes that impede agricultural production, livelihood diversification will be required. When farming is impossible, livelihood diversification strategies may include migration to more populated centres to access opportunities (Rabbani *et al.*, 2013).

4.4.4 Migration

Climate change impacts will render some places difficult for lives and livelihoods, forcing families and individuals to leave their homes When loss and damage to ecosystem services makes it no longer possible to make a living, individuals within households are sometimes forced to migrate. When loss and damage to ecosystem services makes it no longer possible for an entire community to occupy a place, then relocation becomes necessary. While migration and displacement represent two very different types of human mobility, policies can be implemented to ease the burden associated in both cases (Cutter *et al.*, 2012).

Consensus has grown that human mobility will be affected by, and in turn will affect, the ways in which countries adapt to environmental changes linked to climate change (Zetter *et al.*, 2012; Cutter *et al.*, 2012; Martin and Warner 2012). Some migrations resemble patterns familiar from cultural origin stories or national histories, but other relocations occur in circumstances of complex humanitarian crises, particularly where climate change exacerbates other environmental hazards. Climatic stressors interact with local environmental factors and social contexts to shape mobility decision-making, processes, and outcomes (Kniveton *et al.*, 2012; Piguet, 2012; McLeman *et al.*, 2010; Warner *et al.*, 2012). The people most exposed to environmental stressors—particularly farmers, herders, pastoralists, fishers and others who rely on natural resources and the weather for their livelihoods—may be the least able to move very far away, if at all (Betts, 2010).

Women in Turkana, Kenya. Mobility can be a challenge for many vulnerable community members.

Photo Credit: Zinta Zommers

The range of human mobility issues related to climate change is increasingly a subject of national and international policy discussions. Three types of mobility forms mentioned in international climate agreements include human migration, displacement, and planned relocation. As the institutional arrangements for adaptation, as well as loss and damage, continue to be shaped, human mobility will expand from a topic for discussion towards a topic for policy and operations. This will have meaning for development cooperation focused on livelihoods, humanitarian and disaster risk reduction work, urban and rural planning, and similar work for adaptation.

In scenarios of the world beyond 2° C, the climate change impacts combined with other drivers—such as world population growing to 9 billion by 2050, changes in technology, continuing inequalities, and other unforeseen shifts in society—could require a new approach or forum for discussions of migration, displacement, and planned relocation. In coming decades, the way countries manage adaptation will drive patterns of population distribution to marginal destinations that are highly vulnerable to climate change. Particularly vulnerable areas include mountain regions, densely populated deltas, and arid and semi-arid locations where rain-fed crop and livestock production are already under pressure (De Sousa *et al.*, 2015). A more nuanced understanding of how climate change and other variables interact to affect migration, displacement, and planned relocation will help shape adaptation investments to ensure that human mobility contributes to increased resilience to climate change. Research to understand migration patterns in Bangladesh in the aftermath of 2013's cyclone Mahasen used cell phone data to uncover significant information about how many people migrated, to where, and for how long (Lu *et al.*, 2016). Policies addressing migration, displacement, and planned relocation must evolve to manage these changes, if the aim is to make mobility an adaptive alternative that enhances, rather than undermines, climate resilient development. The Paris Agreement has established a task force on human displacement to be overseen by the Executive Committee of the Warsaw International Mechanism (UNFCCC, 2016). Understanding the role of loss and damage to ecosystem services in migration and displacement is important in developing and implementing appropriate policy interventions.

4.5 Addressing non-economic loss and damage

The concept of non-economic loss and damage (NELD) captures the impacts of climate change that are hard to quantify and often go unnoticed by the outside world, such as the loss of traditional ways of living, cultural heritage and biodiversity. It also encapsulates losses whose valuation raises ethical concerns such as loss of life and human health (Serdeczny *et al.*, 2016b).

In all of the case studies, NELD was experienced. Both the heat wave in India and the floods in India and Pakistan led to a loss of life and displacement. In the Sahel and the Horn of Africa, changing rainfall patterns have necessitated migration and in some cases prompted refugee crises. The losses associated with migration and displacement are significant and include a loss of social identity and sense of place. Typhoon Haiyan caused a significant loss of life and displaced millions of people. The trauma associated with a storm of this magnitude and with losing loved ones is long-lasting. In the case of the California drought a lack of potable water has led to an increased incidence of disease. The drought has led to migration and exacerbated the vulnerability of poor and undocumented farm workers who cannot access social protection schemes. Cultural losses, such as the loss of traditional livelihood systems or religious and cultural places of significance, were also confirmed in the case studies.

NELD hold either intrinsic or instrumental values for those affected. The value of NELD is context-dependent and as such very difficult to assess and address. NELD can guide decision making through multi-criteria decision analysis, because that method encompasses components that are not based in monetary valuation–an advantage over reliance on cost-benefit analyses (Fankhauser *et al.*, 2014; Serdeczny *et al.*, 2016b). These questions are not only important research questions but also stimulate critical discussion about how to handle losses whose values are not shared universally (Kakahel, 2015).

While building resilience to climate change will play an important role in averting, reducing and addressing loss and damage, targeted approaches will be needed to address permanent losses and NELD such as cultural losses, including the loss of a sense of place or loss of tradition (Serdeczny *et al.*, 2016b). Approaches to address NELD should be incorporated into comprehensive management frameworks. However, much more needs to be understood about how to address NELD before this can be done (Serdeczny *et al.*, 2016b).

4.6 Conclusion

A range of tools and measures can be employed to avert, minimize, and address loss and damage to human well-being as a result of changes in ecosystem services related to climate change. Decision makers will need a better understanding of the potential magnitude and location of climate change impacts to implement comprehensive risk management frameworks that span the spectrum from averting and reducing to addressing loss and damage. Enhanced understanding of loss and damage to ecosystem services and the impact on human well-being is also crucial for informing policy responses.

The UNFCCC, Sustainable Development Goals, and the Sendai Framework for Disaster Risk Reduction can be viewed as a holistic framework through which loss and damage can be addressed (Roberts *et al.*, 2015). However, much more needs to be known about how to synergize these agendas to simplify rather than complicate national policy processes. Increasing international efforts to support developing countries to avert, minimize, and address loss and damage–including through the Warsaw International Mechanism–will be a basic requirement for managing the consequences of climate change.

And manage we must. Decisions formulated today about supporting societies and communities in vulnerable locations, and the ecosystem services we all depend upon, will determine whether they can adapt or whether they fall into the category of loss and damage. Ultimately, much more action needs to be taken to avoid the unmanageable, manage the unavoidable, and minimize inevitable loss and damage.

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