Mekong River Commission

Climate Change and Adaptation Initiative

Report on the Status of Climate Change and Adaptation in the Lower Mekong Basin

Version 0.4

May 2017

Table of Contents

Executive Summary

It is widely recognised that global climate change is occurring and that this a result of the influence of human activities increasing the concentration of greenhouse gases in the atmosphere. Climatic change is also evident across the Lower Mekong Basin, with rising temperatures, increasing precipitation and rising sea-levels evident over the historical record. The impact of these changes on natural resources and socio-economic systems is currently less clear, but anticipated to become more visible and significant over time, particularly as the projected future climate change across the Lower Mekong Basin is extreme under some scenarios. The expected perturbations on water and water-related sectors from regional climate change have the potential for serious negative impacts on peoples' livelihoods and food security, especially those people in vulnerable communities with a heavy reliance on natural resources and the traditional bounty of the Mekong River and its tributaries.

The approach to assessing the basin-wide impacts of and vulnerability to climate change undertaken by the Mekong River Commission has been to examine a wide range of potential, and equally plausible, future climate scenarios. This approach recognises that there is inherent uncertainty associated with considering future circumstances and allows for the consideration of adaptation options which respond to a wide range of potential future climate conditions. In time, the scenario upon which the region is tracking and the rate of change will become increasingly evident, allowing a narrowing and focusing of adaption actions that are best designed to build a more resilient Lower Mekong Basin community faced with significant challenges.

The purpose of this report, as the first in what is planned to be a triennial update, is to document change over time, to examine and present the change that has already occurred and that which is expected to occur based on the best available knowledge and updated scenario modelling. Documenting the direction, magnitude and rate of change is an important input to national considerations of adaptation responses, both individually and collectively, with a focus on transboundary measures. This information will inform regional cooperation and knowledge sharing including through the development, implementation and ongoing refinement of the Mekong Adaptation Strategy and Action Plan (MASAP).

This report draws principally on the core assessment work of the Mekong River Commission's Climate Change and Adaptation Initiative which has undertaken basin-wide impact assessments of climate change on seven core socio-ecological components of the Lower Mekong Basin: hydrology, flood, drought, hydropower production, ecosystems and biodiversity, fisheries production, and agriculture and livestock production. Taken together, the latter two are used to consider climate change impacts on regional food security. In addition, a regional policy review has considered the enabling environment for adaptation options that will be developed through the MASAP. While this work is the core of this status report, where relevant and appropriate additional studies and literature has also been drawn upon to complement the core assessment work and provide a more complete picture of the state of climate change knowledge as it relates to the region.

Key messages

As summarised in Table ES1, a review of existing information available at the time of this Status Report indicates that:

- Average annual basin-wide temperatures and precipitation have increased over the historical record. Sea-level around the Delta is rising. Regional climate change is not a future phenomenon, it is already occurring.
    - o There are nevertheless regional variations, with areas in the north of the basin and around the Delta becoming drier and areas around Tonle Sap and the southern highlands becoming wetter, particularly during the wet season.
    - o There is no evidence to-date of more intense rainfall events or more frequent or intense tropical storm activity. Indeed storm intensity may be decreasing.
- The hydrology of the Mekong River is changing. Dry season flows are higher and wet season flows lower. This change is most evident in the upper reaches of the Mekong with the effect diminishing downstream, but is unlikely to be the result of climate change. Changes have been principally attributed to up-stream flow modifications by the construction of dams in the Upper Mekong Basin.
- Over recent decades there have been very significant changes in vegetation cover, forests, biodiversity and ecosystems across the Lower Mekong Basin. Large areas of natural vegetation and forests have been lost or significantly degraded, the number of threatened species is increasing, species populations are in decline and natural wetlands have been heavily modified if not destroyed. However, it is not possible from the existing information to determine the relative contribution of climate change to these changes.
    - o The impact from legal and illegal logging, clearing for agriculture and urban areas, flow modification, and over harvesting amongst a range of other pressures are a more significant cause of the changes observed to-date.
- Changes to capture fisheries are uncertain. While overall catch appears to be increasing, the composition of the catch is changing with some species in decline, others increasing, and smaller fish making up a greater portion of the overall catch. Catch-per-unit-effort is declining suggesting there are more people chasing fewer fish. It is not possible at this point in time to determine if climate change has contributed to any of these changes.

While there is evidence that the climate of the region is changing, on average becoming hotter and wetter, a wide range of potential future changes is projected to occur over the next 15 to 45 years:

- Temperatures are projected to increase across the basin and across seasons. The only real uncertainty is the magnitude of the increase and how quickly it occurs. By 2060 the average annual basin-wide increase could be as low as 0.3˚C or as high as 3.3˚C depending on the global emissions trajectory that is followed.
- Rainfall could increase or decrease and with significant variation in the magnitude of change and the location of impacts. Average basin-wide change in dry season rainfall is projected to vary between -23% to +23% by 2060 and wet season rainfall between -18% to +16%. Regional variations are likely to see much wetter average annual conditions in the north of the basin under a wetter overall scenario, and drier average annual conditions from the north, over the Khorat plateau and across the Tonle Sap region, in a drier overall scenario.
- Variations in hydrology will follow changes in precipitation and a similarly wide range of future impacts is possible. Overall basin water yield, annual river flow and level, wet season duration, peak flow and level, and dry season minimum flow and level, could all either increase or decrease depending on the emissions trajectory and the climate change model which turns out

to be most accurate. The range in possible outcomes is enormous with annual river flow changing by between -59% and +33%, and dry-season minimum one-day flow changing by between -65% and +42% at Chiang Saen under climate change only scenarios. Basin development will interact with the impacts from climate change, in some cases exacerbating the change and in some cases mitigating against it.

The contribution of climate change to past and current changes in socio-economic systems has not been determined with any certainty. There are too many other factors at play. However, projected changes are potentially very significant and many people and communities are vulnerable to potentially wide-ranging impacts:

- Agricultural yields are likely to be affected with the negative impacts outweighing the positive. Potential declines in rice yields are of particular concern. Planned increases in irrigation, changes in agricultural practice and technological improvements are likely to be required to offset these impacts.
- Yields from fisheries and aquaculture are also vulnerable but impacts could be either positive or negative. While aquaculture is often considered more vulnerable due to rising sea-levels, salinity intrusion and the impacts of increased temperatures, floods, and droughts on smaller ponds and reservoirs, basin-wide impacts on capture fisheries in flooded habitats are projected to be the most significant.
- Hydropower production in both the mainstream and tributaries is at risk due to increased drought frequency although changes could be positive or negative depending on the scenario.
- Navigation may be affected by lower dry season flows making some parts of the upper Mekong impassable at certain times of year. Roads and water supply infrastructure are at risk from more intense rainfall, increased flooding and landslides, while significant expenditure may be required to protect coastal infrastructure from rising sea levels and storm surges.
- Overall, food security has improved significantly in recent decades, the health of the population is better, poverty levels have fallen dramatically, the population is more urbanised and fertility rates have fallen. However, many households and communities along the Mekong corridor remain vulnerable to shocks, particularly droughts and floods which can have a material impact on their livelihoods. Future climate change is likely to exacerbate the losses from extreme events with greater numbers of people likely to be affected by larger flooding events in future.
- Without action to mitigate the impacts, the costs of climate change could be significant with large parts of the economy at risk; however, the impacts will not be felt evenly as some people and communities are more exposed than others or will experience the changes sooner or to a greater extent. Provinces in Cambodia and Lao PDR are generally more vulnerable due to higher dependency ratios and higher poverty rates, especially in the north of the LMB, and around Tonle Sap and the southern highlands.
- There are broad economic and structural changes occurring across Lower Mekong Basin countries which will help to mitigate the impacts of climate change (i.e. economic growth, urbanisation, reducing poverty and improving health and infrastructure). However, some policies such as those favouring resource extraction which degrade natural ecosystems, may be in conflict with adaptation measures, reducing the buffering capacity of these systems. Despite the changes that have occurred, many people are still very reliant on natural systems for their livelihoods and food security, which makes them more vulnerable to impacts on these systems.

Table ES1: Summary of historical and projected basin-wide change and key vulnerabilities

		Historical basin-wide change	Due to Climate Change	Projected basin-wide change	Key impacts and vulnerabilities
Climate		↑ temperature ↑ precipitation (but regional variations)	☑	↑ temperature ↑/↓ precipitation	All natural and socio-economic systems.
Natural systems	Water resources	↑ dry season water levels ↓ wet season flows	☒	↑/↓ basin water yields, annual and seasonal flow and water level, wet season duration & peaks, and dry season minimums ↑dry season salinity intrusion	Increased floods and more severe droughts; Salinity intrusion further inland; Change in hydro-biological cues.
Natural systems	Vegetation and forests	↓ natural vegetation ↓ forest cover	☒	-	Reduced adaptive capacity
Natural systems	Biodiversity and ecosystems	↓ species populations ↓ wetland area ↓ terrestrial ecoregions	☒	↓ species and suitable habitats ↑ ecoregions experiencing novel bioclimatic conditions	Reduced adaptive capacity Species extinctions Reduced ecosystem services
Natural systems	Fisheries	↑ overall yields ↓ catch per unit effort Change in species catch composition	☒	↑ vulnerable species ↑/↓ habitat yields	Reduced adaptive capacity Species extinctions
Socio-economic systems	Agriculture and irrigation	↑ agricultural yields ↑ irrigation	☒	↓ Rice and maize yields	Crop yields at risk due to temperature increases, floods and droughts
Socio-economic systems	Fisheries and aquaculture	↑ overall yields ↓ catch per unit effort	☒	↑/↓ yields from capture fisheries and aquaculture; strongly affected by flooding	Aquaculture at risk of temperature, floods, droughts, sea-level rise and water quality
Socio-economic systems	Food security	↑ food security	☒	-	Vulnerabilities in Cambodia and Lao PDR with high poverty rates and high dependency ratios
Socio-economic systems	Energy (hydropower)	↑ hydropower production	☒	↑/↓ positive or negative impacts depending on the scenario	Vulnerable to increased droughts
Socio-economic systems	Navigation & infrastructure	↑ navigation ↑ infrastructure including grid electricity, water supply and sanitation, paved roads	☒	-	Decreases in water level a threat to navigation in upper reaches Roads and water supply infrastructure vulnerable to more intense rainfall, floods and landslides
Socio-economic systems	Human health	↑ human health	☒	-	Water and vector-borne disease; heat stress
Socio-economic systems	Poverty, wellbeing, employment and income	↓ poverty ↓ reliance on agriculture ↑ income	☒	↑ flooding affecting more people ↑ drought frequency and duration in some areas	Provinces of Cambodia and Lao PDR more vulnerable due to high poverty rates, high dependency ratios and greater reliance on agriculture

The wide-range of projected impacts across water and water-related sectors on the basis of equally plausible climate scenarios, with potentially different impacts in different parts of the Basin, means it is essential to identify and implement adaptation policies that:

- have broad socio-economic benefits and rationale, essentially supporting good practice and sustainable development pathways and ensuring resilience to shocks whether they be due to climate change or other causes (e.g. global market volatility, natural disasters – whether or not they become more frequent);
- are flexible and scalable – the direction and magnitude of change cannot be known with certainty. All we know is that significant change is very likely to occur. It is important that communities can deal with change regardless of how it manifests itself and can rapidly scale-up the response as change becomes more evident and severe;
- support improved governance and strengthened institutions that allow for participatory approaches and enhanced decision-making capacity for individuals and communities – a one-size-fits-all approach is unlikely to succeed given the variation in potential impacts across the Lower Mekong Basin and so awareness and access to information is critical for household, business and government decisions;
- support a diversification of income sources and livelihoods wherever possible, so that people have options at times when they really need them; and
- provide for information (including monitoring and early-warning) and capacity building, which is essential to enabling good decisions at all levels of government and community.

A policy review undertaken by the Mekong River Commission to ascertain the enabling environment for adaptation actions found that:

- National policies for adaptation are in place but in some cases are in potential conflict with other socio-economic strategies in particular sectors;
- Policies at a national level are focused at government administration and public awareness and action and less so at the private sector, which has a potentially important role to play;
- Improved information exchange and knowledge sharing would be beneficial both within and between countries;
- National coordination generally occurs through national climate change committees. There may be some room for simplification of governance structures to improve coordination and effectiveness;
- Climate change awareness in countries is generally low, both within government and amongst the broader public;
- Financing for climate change adaptation is growing within national budgets and there is an important role in ensuring this expenditure is coordinated with funds from international assistance programmes; and
- Regional institutions such as ASEAN and the MRC both give priority to climate change work and the importance of cooperation between member countries on the subject. They provide a mechanism for cooperation and transboundary regional action.

Within this context, there are nevertheless many barriers to effective adaptation within Lower Mekong Basin countries. Through their National Communications to the United Nations Framework Convention on Climate Change, all countries have identified issues with:

1. a lack of human resources capacity
2. regional scenarios and information on climate change impacts being inadequate
3. data and information gaps
4. a lack of financial resources and the mechanisms for financing action on climate change
5. insufficient technology transfer and required investment
6. a lack of awareness both within government at different levels, and across the community on potential climate change impacts and adaptation options

Despite this capacity deficit, there are many examples of climate change adaptation being enacted within countries across the region and according to their National Communications, recognition that there is a need to do much more. Access to international finance and regional cooperation and knowledge sharing will play an important role in achieving these ambitions.

Chapter 1: Introduction

1.1 Understanding climate change status, impacts, vulnerability and adaptation measures

Global climate change is widely recognized and human influence on the climate system is clear (IPCC, 2014). Observed changes since the 1950s are unprecedented over decades to millennia with the atmosphere and ocean having warmed, the amount of snow and ice diminished and sea-level having risen (IPCC, 2014). The extent to which changes are also evident at regional and local scales and the direction and magnitude of those changes is less evident and to-date not subject to systematic and comprehensive analysis for the range of important climatic variables. Further, the impacts of any changes in climatic variables across economic sectors and with consideration of the implications for society and livelihoods, is even less studied in any systematic and comprehensive way. This report seeks to bring together a comprehensive picture of what is happening across the Lower Mekong Basin (Figure 1.1) in relation to climate change with consideration of the implications for Member Countries of the Mekong River Commission (MRC). It is anticipated that this will be a regular (triennial) report of the MRC that will be updated and revised over time in-line with new information and knowledge of how the climate is changing, the extent to which that is evident within the region and having an impact on important water-related sectors and vulnerable communities, and what Member Countries are doing both individual and collectively to respond and adapt to the changes that are already occurring and those that are yet to occur. Over time, the Status Report on Climate Change and Adaptation in the LMB will provide inputs to the broader State of the Basin reports prepared periodically by the MRC, as has been the case for the 2016 preparatory State of the Basin report (MRC 2016a).

The report is structured around the broader programme of work of the MRC to assess the basin-wide impacts of climate change on water and water related sectors and the common methodologies and modelling used for that work forms the basis for most of the analysis. However, that information base is supplemented with the results and findings of other relevant studies and assessments, particularly those conducted at a regional scale, to build as comprehensive a picture as possible on climate change and its impacts in the Lower Mekong Basin. Understanding that change which has already occurred and that which is projected to occur under a range of different scenarios will serve as an important resource to Member Countries to consider how best to respond and prepare for further disruption, particularly at a transboundary level where cooperation is essential.

The components of the MRC's suite of basin-wide studies conducted by the Climate change and Adaptation Initiative (CCAI) include an assessment of climate change impacts on the Mekong's flow regime, on food security considering flood and drought prone areas, on ecosystems and biodiversity, on long-term flood management options and on drought risk and vulnerability (Figure 1.2). The main objective of the these basin-wide assessments is to provide information on the impacts of potential future climate change on water and water related natural resources and economic sectors in a way which supports decision-making on climate change adaptation measures at regional and national levels within the MRC Member Countries. In addition to informing this Status Report on Climate Change and Adaptation in the LMB, the assessments will also support the preparation of the Mekong Adaptation Strategy and Action Plan (MASAP) in conjunction with a regional review of policy for climate change and adaptation in the LMB (MRC, 2016b).

Figure 1.1: The Mekong Basin with the Lower Mekong Basin highlighted in red.

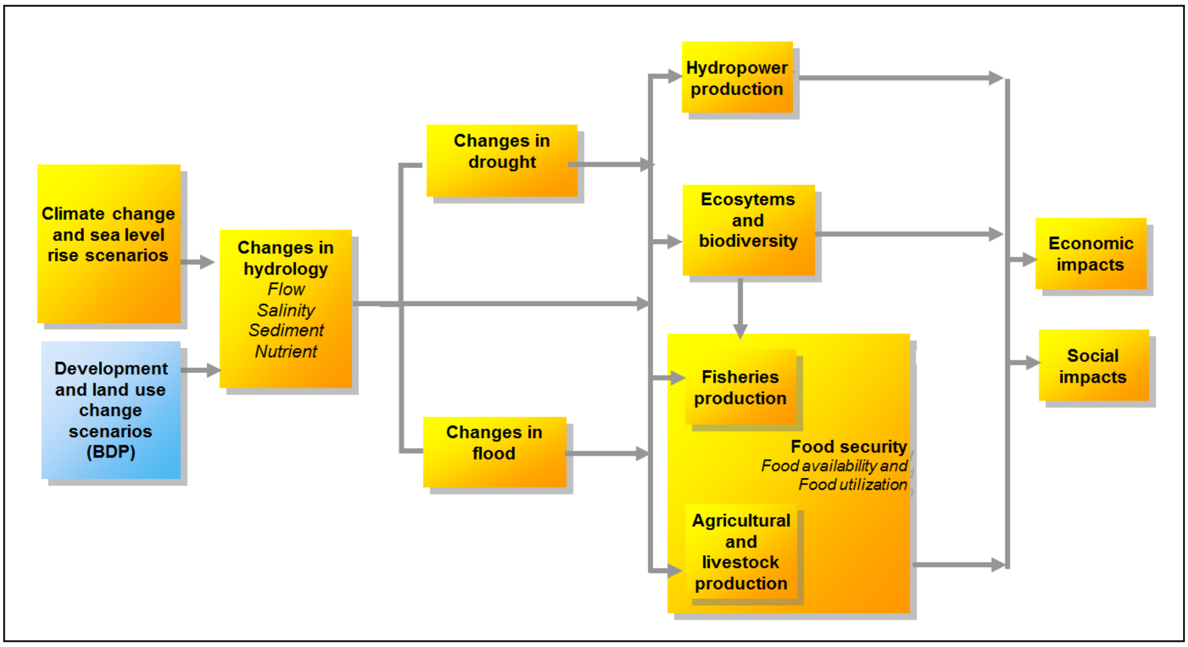


Figure 1.2: Elements of the CCAI basin-wide assessments of climate change impacts on water and water related sectors. *Source: MRC, 2014a*.

The basin-wide assessments of climate change impacts adopt a framework approach which includes three steps as illustrated in Figure 1.3: (1) scoping of the assessment; (2) vulnerability assessment including a baseline assessment under historical climate variations and a scenario assessment under future climate projections; and (3) identification and evaluation of adaptation measures. It is intended that the adaptation measures identified in the basin-wide assessments will be mainstreamed into adaptation strategies and plans (in the case of CCAI in the MASAP), and then implemented, monitored and evaluated.

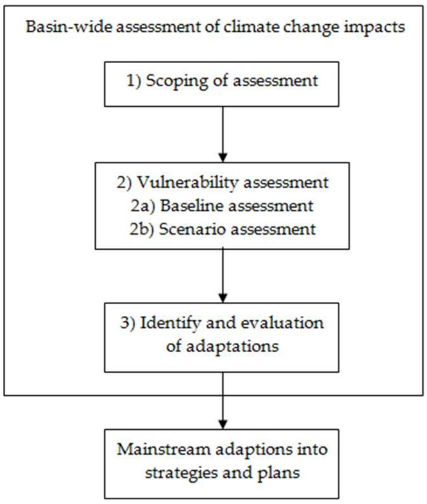


Figure 1.3: Overall approach taken to the basin-wide assessment of climate change impacts (MRC, 2014a).

In line with the guidance from the MRC Joint Committee during its 40th meeting in Phnom Penh in 2014, the geographic scope if the assessments is the entire LMB. It therefore considers both aquatic and terrestrial resources. This approach differs from many other MRC studies which focus mainly on the flow and aquatic resource of the Mekong mainstream. The impacts of climate change are expected to be widespread across the Basin and the interaction of ecosystem components across the landscape is important aspect to consider in adaptation planning. Influences from the Upper Mekong Basin are also considered throughout the report give the impact of snowmelt and other changes in hydrological conditions in China and Myanmar on the hydrology of the Lower Mekong Basin.

The approach taken in this report is that for each relevant water-related sector both the observed trends and changes, if any, and the projected trends and changes under the range of plausible future climate change scenarios, are presented and discussed. This provides information about the impacts of, and vulnerability to climate change in the Basin in sectors important to people's livelihoods including fisheries, agriculture, energy, natural ecosystems. If no change attributable to climate change has been observed, the current conditions are nevertheless presented and will serve as a baseline from which to evaluate future changes in subsequent reports and based on an agreed monitoring programme.

1.2 Climatic, hydrological and other baselines

The climatic baseline period adopted for the MRC's basin-wide assessments is 1981-2010 (centred on 1995). This is consistent with the World Meteorological Organisation's advice that the previous standard reference (1961-1990) be updated to reflect the rising atmospheric concentrations of greenhouse gases now recorded. The baseline or reference period should be representative of the present-day or recent average climate in a study region, and be of sufficient duration to encompass a range of climatic variations, for example, periods of severe drought and flood. The baseline is however, also affected by data availability. As a result, although the climatic baseline used is 1980-2010 the baseline period for other components of the MRC's basin-wide assessments are as indicated in Table 1.1. For hydrological assessment the baseline is 1985-2008.

Table 1.1: Data related to baseline periods (MRC, 2016c).

Type of baseline	Baseline period	Data source(s)	Remarks
Climate	1981-2010	MRC (observed data provided by MCs)	Stations cover whole LMB
Sea level	1985-2008	MRC (observed data provided by MCs)	Available in IKMP
Hydrology	1985-2008	MRC (observed data provided by MCs)	Available in IKMP
Water resources development	2007	MRC (provided by MCs)	Available in IKMP
Land cover	1993, 1997, 2003, 2010	MRC (provided by MCs)	Available in IKMP
Species	2008-2014	IUCN Red List	To be reviewed and updated by the CCAI Ecosystem Assessment Team

1.3 Future scenarios

1.3.1 Climate scenarios

Examining projected future change requires consideration of future climatic scenarios. While an infinite number of scenarios are possible only a small number can be realistically considered and these should encompass the range of plausible future climate projections (MRC, 2015a). The regional results presented in this report, unless otherwise stated, have generally been derived from a small number of well performing Global Circulation Models (GCMs) selected from the SimCLIM database of CMIP5 models that together cover a wide range of changes in both magnitude and patterns of projected temperature and rainfall. The downscaling of global models was undertaken within SimCLIM using pattern scaling and bilinear interpolation (MRC, 2015a).

In order to provide a wide range of climate change projections three emissions scenarios were selected from the four Resource Concentration Pathways developed for IPCC AR5 (IPCC, 2014). Combining the three emissions scenarios with the three model scenarios, results in nine climate scenarios covering the range of plausible climate change in the Lower Mekong Basin for the period to 2100.

The nine climate scenarios represent: i) three magnitudes of climate change due to low, medium and high carbon emissions in the future; and ii) three seasonal patterns of climate change including an increase in precipitation in both dry and wet seasons (‘wetter overall’), a decrease in precipitation in both dry and wet seasons (‘drier overall’) and an increase in precipitation in the wet season but a decrease in the dry season (‘increased seasonality’). The nine scenarios are as follows.

Low climate change scenarios are associated with low future carbon emission scenarios (RCP2.6):

> *Scenario 1: Drier overall-low* represents a slight decrease of basin-average precipitation in both wet and dry seasons in the future. The scenario is formulated using low emission scenario (RCP2.6), GISS-E2-R-CC GCM and low climate sensitivity;
>
> *Scenario 2: Wetter overall-low* represents a slight increase of basin-average precipitation in both wet and dry seasons in the future. The scenario is formulated using low emission scenario (RCP2.6), GFDL-CM3 GCM and low climate sensitivity
>
> *Scenario 3: Increase seasonality-low* represents a slight increase in basin average precipitation in the wet seasons and a slight decrease in dry seasons in the future. The scenario is formulated using low emission scenario (RCP2.6), IPSL-CM5A-MR GCM and low climate sensitivity.

Medium climate change scenarios are associated with medium future carbon emission scenarios (RCP6.0):

> *Scenario 4: Drier overall-medium* represents a medium decrease of basin average precipitation in in both wet and dry seasons in the future. The scenario is formulated using medium emission scenario (RCP6.0), GISS-E2-R-CC GCM and medium climate sensitivity;
>
> *Scenario 5: Wetter overall-medium* represents a medium increase of basin average precipitation in both wet and dry seasons in the future. The scenario is formulated using medium emission scenario (RCP6.0), GFDL-CM3 GCM and medium climate sensitivity
>
> *Scenario 6: Increase seasonality-medium* represents a medium increase of basin-average precipitation in wet seasons and a medium decrease in in dry seasons. The scenario is formulated using medium emission scenario (RCP6.0), IPSL-CM5A-MR GCM and medium climate sensitivity.

High climate change scenarios are associated with high future carbon emission scenarios (RCP8.5):

Scenario 7: Drier overall-high represents a large decrease of basin-average precipitation in both wet and dry seasons in the future. The scenario is formulated using high emission scenario (RCP8.5), GISS-E2-R-CC GCM and high climate sensitivity;

Scenario 8: Wetter overall-high represents a large increase of basin-average precipitation in both wet and dry seasons in the future. The scenario is formulated using high emission scenario (RCP8.5), GFDL-CM3 GCM and high climate sensitivity

Scenario 9: Increase seasonality-high represents a large increase of basin average precipitation in wet seasons and a large decrease in dry seasons. The scenario is formulated using high emission scenario (RCP8.5), IPSL-CM5A-MR GCM and high climate sensitivity.

In examining climate change impacts on ecosystems and biodiversity a multi-model ensemble was also run using a combination of thirteen GCMs that also encompass the three scenarios (Table 1.2).

Table 1.2: The list of CIMP-5 Earth System Models used in the multi-model ensemble analysis and the three models identified for the LMB scenario analysis for assessing the impacts on ecosystems and biodiversity (MRC, 2017a).

Model	**Code**	Scenario
ACCESS1.0	ae	
CanESM2	ca	
CCSM4	cc	
CMCC-CM	cm	
CNRM-CM5	cn	
GFDL-CM3	**gf**	**Wetter**
GFDL-ESM2M	gd	
GISS-E2-R-CC	**gs**	**Drier**
IPSL-CM5A-LR	is	
IPSL-CM5A-MR	**ip**	**Seasonality**
MIROC5	mo	
MPI-ESM-LR	mp	
NorESM1-M	no	

The timeframe for projected impacts are aligned with the basin-wide development scenarios developed for the MRC Basin Development Plan 2 (see following section): that is, the near-term future centred on 2030 (2021-2040); and the medium-term future centred on 2060 (2051-2070).

Sea-level rise projections were found not to vary significantly between GCM (MRC, 2015a) and so a single model (‘wetter overall’), coupled with low (RCP2.6), medium (RCP4.5) and high (RCP8.5) emissions scenarios was selected for assessment of impacts and vulnerability in the Mekong Delta region. The projected sea-level rise scenarios are shown in Table 1.3.

Table 1.3: Selected sea-level rise (metres) projection scenarios (MRC, 2016c).

	Emissions scenario		
Period	**Low emissions (RCP2.6)**	**Medium emissions (RCP4.5)**	**High emissions (RCP8.5)**
2030 (2021-2040)	0.13	0.15	0.16
2060 (2051-2070)	0.30	0.33	0.40

1.3.2 Basin-wide development scenarios

Development scenarios referred to in this report are those developed during the MRC Basin Development Plan 2 process (2009-2011) to represent different combinations of nationally planned sector development, with a focus on active water use including domestic and industrial, irrigation, hydropower and flood control (MRC, 2011). These are the sectors that were identified by the MRC Member Countries as the most important for further water resourced development, as well as having the greatest risk of transboundary environmental and social impacts. Nine basin-wide development scenarios were formulated for four different time horizons: baseline (2000); definite future (2000-2015); foreseeable future (2015-2030); and long-term future (2030-2060) (Table 1.4). For the purposes of assessing climate change impacts in conjunction with projected development, two development scenarios were selected and agreed with Member Countries:

- the foreseeable future (2030) 20-year plan scenario (No. 4); and
- the long-term development (2060) scenario (No. 8).

Table 1.4: Basin-wide development scenarios as developed for MRC BDP2 process (MRC, 2011).

No.	Short Title	Full Title	Development Period	Interventions/Projects
Baseline situation				
1	**BS**	Baseline Scenario		Year 2000 infrastructure including existing HEP dams
Definite future situation				
2	**2015-UMD**	Upper Mekong Dam Scenario	2000 - 2015	Baseline extended to include the full HEP cascade on the Lancang
3	**2015-DF**	Definite Future Scenario	2000 - 2015	2015-UMD plus 26 additional HEP dams in LMB and 2008 irrigation and flood measures
Foreseeable future situation				
4.0	**2030-20Y**	LMB 20-Year Plan Scenario	2010 - 2030	2015 DF plus 11 LMB mainstream dams and 30 planned tributary dams, irrigation, and water supply
4.1	**2030-20Y+CC**	LMB 20-Year Plan Scenario Climate change	2010 - 2030	As above plus climate change for average year between 2010-30 and 17cm sea level rise[4]
5	**2030-20Y-w/o MD**	LMB 20-Year Plan Scenario without mainstream dams	2010 - 2030	As above, excluding 11 LMB mainstream dams
6.1	**2030-20Y-w/o LMD**	LMB 20-Year Plan Scenario with 6 mainstream dams in Northern Lao PDR	2010 - 2030	As above plus 6 LMB mainstream dams in upper LMB
6.2	**2030-20Y-w/o TMD**	LMB 20-Year Plan Scenario with 9 mainstream dams, excl. Thailand	2010 - 2030	2030-20Y, excluding the two Thai mainstream dams
6.3	**2030-20y-w/o CMD**	LMB 20-Year Plan Scenario with 9 mainstream dams, excl. Cambodia	2010-2030	2030-20Y, excluding the two Cambodian mainstream dams
7	**2030 – 20Y Flood**	Mekong Delta Flood Management Scenario	2010 - 2030	Baseline plus 3 options for flood control in Cambodia and Viet Nam Delta
Long term future situation				
8.0	**2060-LTD**	LMB Long-term Development Scenario	2030-2060	2030-20Y plus further infrastructure developments in LMB
8.1	**2060-LTD+CC**	LMB Long-term Development Scenario Climate change	2030-2060	As above plus climate change for average year between 2030-50 and 30cm sea level rise
9	**2060–VHD**	LMB Very High Development Scenario	2030-2060	As 2060-LTD, extended to full potential infrastructure developments

1.4 Uncertainties in climate change projections

There are inherent uncertainties in the development of climate change scenarios and the projection of future outcomes. Uncertainty can result from a wide range of sources. According to the IPCC (2014) "*uncertainties in the past and present are the result of limitations of available measurements, especially for rare events, and the challenges of evaluating causation in complex or multi-component processes that can span physical, biological and human systems. For the future, climate change involves changing likelihoods of diverse outcomes. Many processes and mechanisms are well understood, but others are not. Complex interactions among multiple climatic and non-climatic influences changing over time lead to persistent uncertainties, which in turn lead to the possibility of surprises*".

Several recent studies have reviewed the uncertainties associated with the use of GCMs and the implications of those uncertainties for climate change impact assessments (e.g. Parry *et al.*, 2007; Randall *et al.,* 2007; Stainforth *et al.,* 2007; Koutsoyiannis *et al.,* 2008, 2009; Blöschl and Montanari, 2010; Montanari *et al*., 2010; Kiem and Verdon-Kidd, 2011; Stephens *et al*., 2012). These studies demonstrate that while climate models may represent the 'best available science' in terms of our understanding into global climate processes, the inherent uncertainties mean that climate model outputs do not predict the future, they represent simply a projection of potential future outcomes based on set of input parameters and assumptions. Awareness of this is important when considering risk-based responses to climate change and its potential impacts. For a more complete description of uncertainties associated with the use of GCMs, the selection of baseline data, the processing of GCM outputs and methods for down-scaling global projections to regional projections, see MRC (2015a).

Science is uncertain and always will be – and climate science is no exception – but this does not have to prevent decisions from being made. Very often decisions are made under uncertainty or with only partial knowledge about likely consequences (e.g. investment decisions, career decisions, decisions concerning our health etc.). However, when it comes to climate science many are reluctant to consider climate change adaptation until the science is more certain (e.g. Jacobs *et al*., 2005; Kiem and Austin, 2013a; 2013b). To assist timely and meaningfully adaptation novel frameworks for climate adaptation decision making under uncertainty and research aimed at translating uncertainty into risk are therefore urgently required because uncertainty surrounding climate science is unlikely to disappear.

Much can be learned from the extensive body of knowledge relating to assessing and dealing with climate risks (i.e. climate risk in general as opposed to impacts and risks associated with anthropogenic climate change). The majority of this climate risk work pre-dates the emphasis on climate change adaptation (e.g. Hammer *et al.* 2000; Hayman 2000; Cash *et al.* 2003; McKeon *et al.* 2004; Adger *et al.* 2005; Meinke *et al.* 2006, 2009; Hayman *et al.* 2007). Decision makers prefer certainty but in reality have to cope with uncertainty all the time (not just uncertainty related to climate) and climate change adaptation is about providing decision makers with the insight and tools needed to do that.

Uncertainties need to be recognized and considered in adaptation planning (MRC, 2015a). It is because of this uncertainty, however, that the MRC's basin-wide assessments have used a selection of scenarios that provide a range of equally plausible impacts. As no single scenario is considered more likely than the others, it is necessary to examine the range of potential scenarios in order to understand the range of potential future impacts and best prepare for the range of disturbances that may eventuate.

The climate models used for the MRC basin-wide impact assessment studies reported herein are an improvement on previous versions (IPCC, 2014). However, they perform better for some parameters than for others. The models perform less well for large scale patterns of precipitation in particular, than they do for surface temperatures (IPCC, 2014). While improvements have also been made in sea-level projections, challenges nevertheless remain in representing the Greenland and Antarctic ice sheets (IPCC, 2014).

Chapter 2: Observations and projections of change in climatic variables

Key findings

Over recent decades average basin-wide temperature and precipitation have increased. Changes in rainfall are geographically varied with the main areas of increase located around Tonle Sap and the southeastern highlands. Areas in the north of the LMB and around the Delta are generally drier. There is no evidence of any change in rainfall intensity or tropical storm activity.

The LMB is projected to warm significantly by mid-century across all seasons and under all scenarios and models. Annual increases range from 0.4°C to 3.3°C by 2060. Precipitation is projected to either increase or decrease depending on the model selected. Average basin-wide change in dry season rainfall is projected to vary between -23% to +23% by 2060 and wet season rainfall between -18% to +16%. Regional variations are likely to see much wetter average annual conditions in the north of the basin under the wetter overall scenario, and drier average annual conditions from the north, over the Khorat plateau and across the Tonle Sap region in the drier overall scenario.

2.1 Global Observations

The Intergovernmental Panel on Climate Change (IPCC) finds in its fifth assessment report (IPCC, 2014) that "*the warming of the climate system is unequivocal and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen*".

In the northern hemisphere, it is likely that the period from 1983 to 2012 was the warmest 30-year period of the last 1400 years. The globally averaged combined land and ocean surface temperature shows a warming trend of 0.85˚C over the period 1880 to 2012 based on an assessment from multiple independently produced datasets (IPCC, 2014).

The IPCC (2014) identifies that ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90 per cent of the energy accumulated between 1971 and 2010, with only about one per cent stored in the atmosphere. Although precipitation averaged over mid-latitude land areas of the northern hemisphere has increased, there is low confidence of long-term positive or negative trends in precipitation in other areas. Greenland and Antarctic ice sheets have been losing mass, annual mean Arctic sea-ice extent has decreased and sea-level has been rising. Over the period 1901 to 2010, global mean sea-level rose by 0.19 m with the rate of rise since the mid-19th century being larger than the mean rate during the previous two millennia (IPCC, 2014).

Rises in global temperatures and increases in sea-level have been accompanied by rises in the concentration of greenhouse gases in the atmosphere (Figure 2.1) as a result of human activity, with the IPCC (2014) concluding that the effects of high atmospheric concentrations of these gases, together with other anthropogenic drivers are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.

Anthropogenic greenhouse gas emissions continued to increase between 1970 and 2010 with larger absolute increases between 2000 and 2010 (Figure 2.2). In 2010 they reached 49 ±4.5 $GtCO_2$-eq/yr.

Economic and population growth continue to be the most important global drivers of increases in CO_2 emissions from fossil fuel combustion. While the contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, the contribution from economic growth rose sharply (IPCC, 2014).

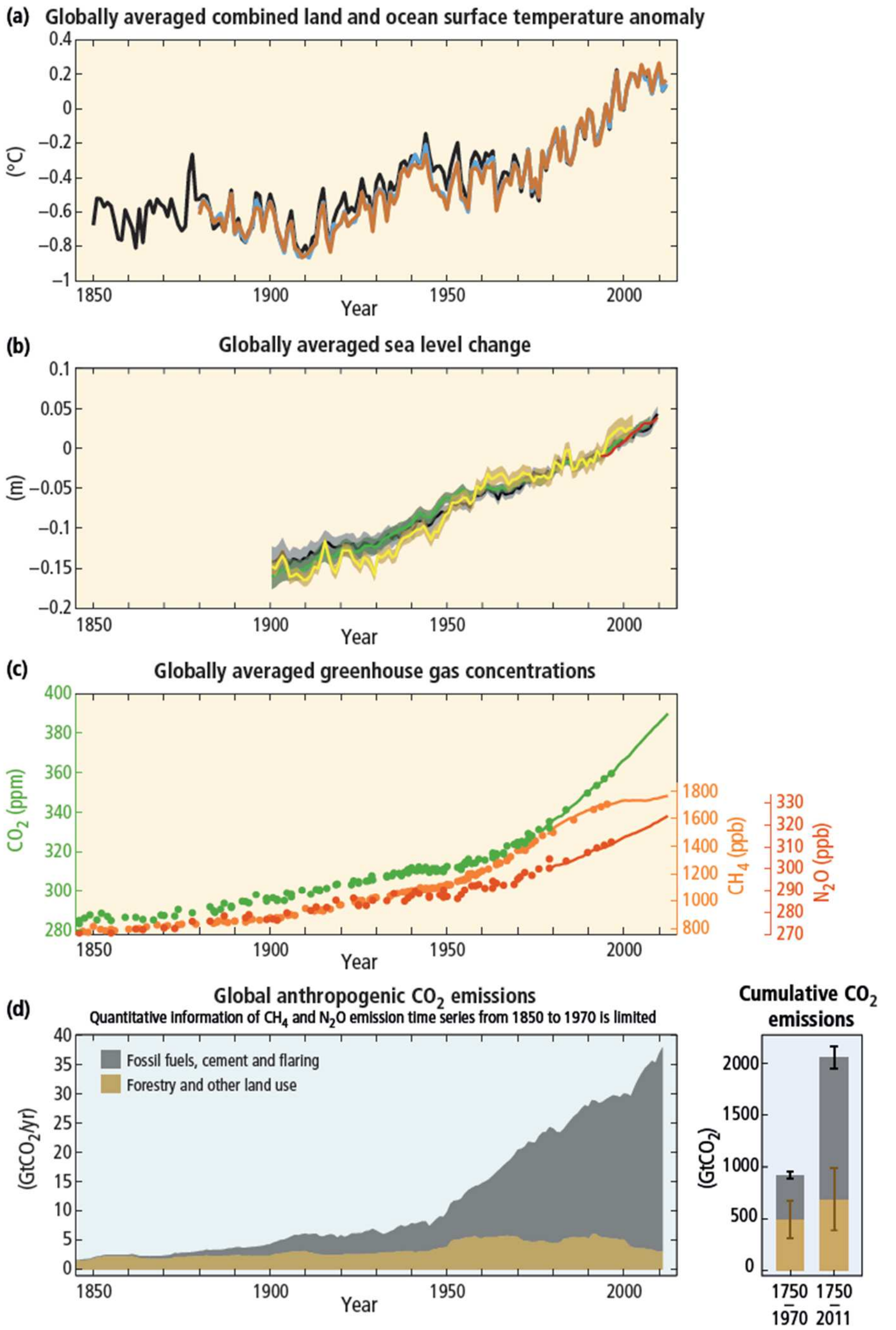


Figure 2.1: Observations and other indicators of a changing global climate system: (a) annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005; (b) annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest running dataset; (c) atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) determined from ice core data and from direct atmospheric measurements; (d) global anthropogenic CO_2 emissions from forestry and other land use as well as from burning fossil fuel, cement production and flaring. *Source: IPCC (2014).*

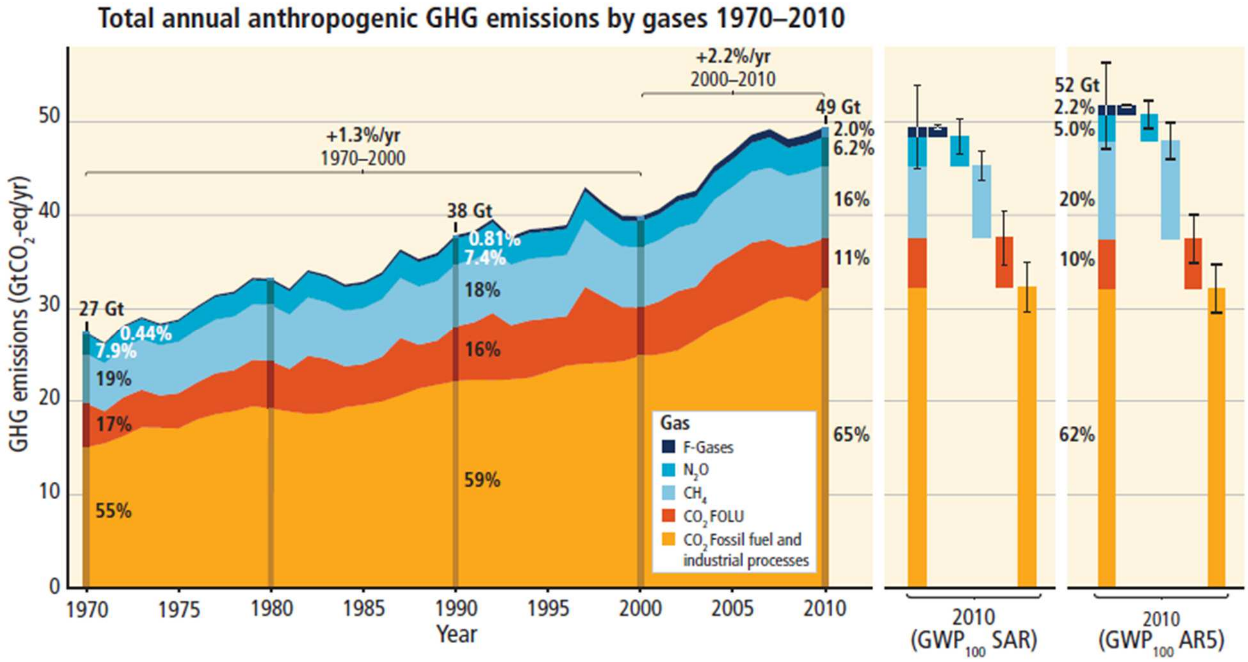


Figure 2.2: Total annual global greenhouse gas emissions for the period 1971 to 2010 by gases: CO2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); and fluorinated gases (F-Gases). *Source: IPCC (2014).*

The US National Oceanic and Atmospheric Administration's (NOAA) Annual Greenhouse Gas Index (AGGI) is a yearly report on the combined influence of long-lived greenhouse gases, such as carbon dioxide and methane that absorb and radiate heat, on the Earth's surface temperature. The index compares the warming influence of these gases each year to their influence in 1990, the year that countries who signed the UN Kyoto Protocol agreed to use as a benchmark for their efforts to reduce emissions. In 2010, the index stood at 1.29. By the end of 2013, the warming influence of greenhouse gases had risen 34 percent above the 1990 baseline. It has also shown a continued steady upward trend that began with the Industrial Revolution of the 1880s.

The AGGI identifies the change in the cumulative influence of the major long-lived greenhouse gases present within the atmosphere rather than the change in the annual emissions of those gases. It is a global index from which it is not possible or useful to disaggregate regional variations. However, the change in overall concentration of those gases in the atmosphere and their influence on global warming is affected by changes in the emissions. The AGGI results for 2014 show that Carbon Dioxide (CO_2) dominates the total forcing with Methane (CH_4), Nitrous Oxide (N_2O) and the CFCs becoming relatively smaller contributors to the over time[1].

Evidence of climate change impacts is widespread, being strongest and most comprehensive for natural systems (Figure 2.3; IPCC, 2014). Changing precipitation or melting snow and ice has affected hydrological systems. Many terrestrial, freshwater and marine species have shifted their geographic range, seasonal activities, migration patterns and abundances. Impacts in human systems have also been

[1] http://www.esrl.noaa.gov/gmd/aggi/aggi.html

felt with the negative impacts of climate change on crop yields reported as more common than the positive impacts (IPCC, 2014).

The IPCC (2014) reports that there has been a change in many extreme weather and climate events since around 1950 including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. It notes that it is likely the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It identifies that there is medium confidence that the recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at a regional scale (IPCC, 2014). While an increase in intensity of cyclones/hurricanes in the north Atlantic has been observed, there is low confidence of an increase in tropical storm activity elsewhere (IPCC, 2014).

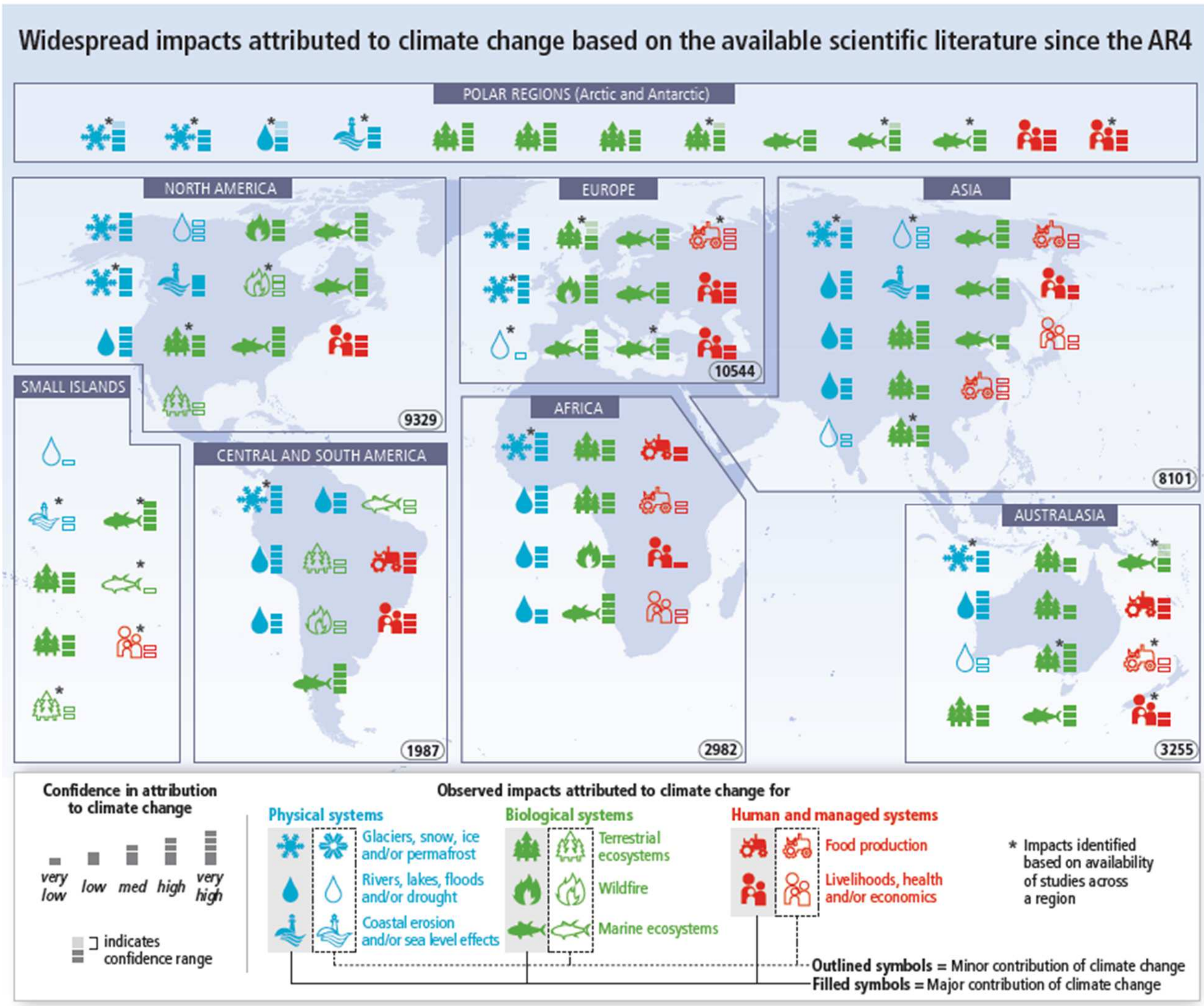
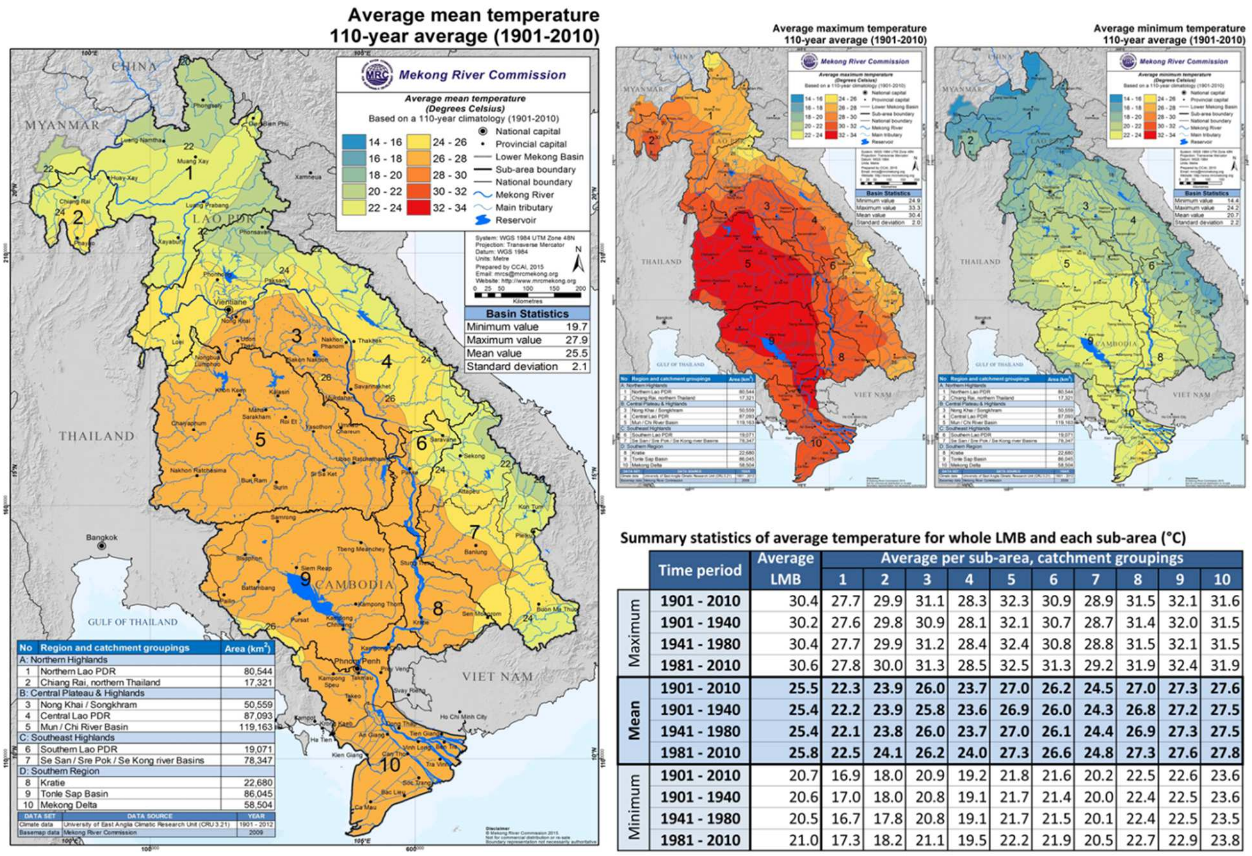


Figure 2.3: Observed impacts of climate change since the IPCC Fourth Assessment Report (AR4) based on the available scientific evidence. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010 based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words. *Source: IPCC (2014).*

2.2 Regional Historical Observations

2.2.1 Historical temperature and rainfall

Average annual temperatures across the Lower Mekong Basin (LMB) range from a minimum of 22.3˚C in Northern Lao PDR to a maximum of 27.6˚C in the Mekong delta, over the period 1901-2010 (Figure 2.4). This meridional, north-to-south, temperature gradient is unsurprising, given that northerly parts of Lao PDR have elevations that are 1000 metres higher than in the southern regions. It is these same thermal contrasts - particularly across the Tibetan Plateau - that drive the monsoon circulation. Average maximum and minimum temperatures are similarly controlled by elevation.



Summary statistics of average temperature for whole LMB and each sub-area (°C)

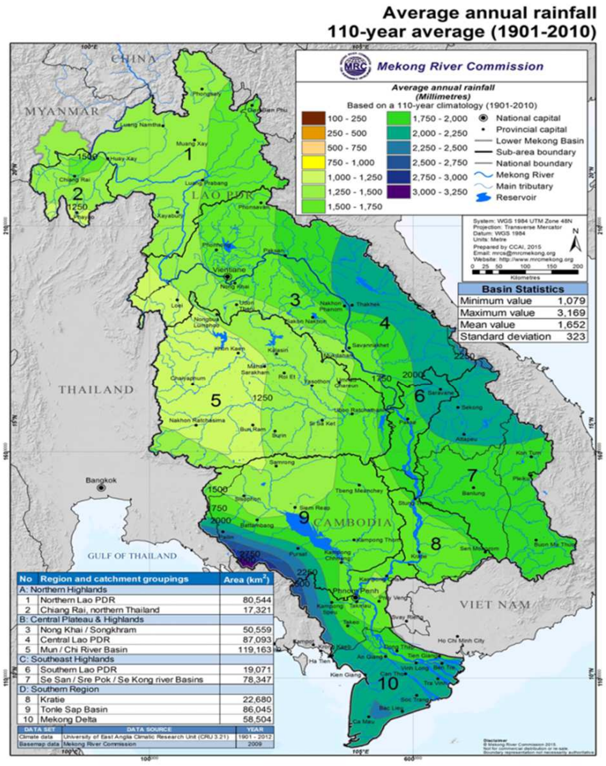
	Time period	Average LMB	Average per sub-area, catchment groupings									
			1	2	3	4	5	6	7	8	9	10
Maximum	1901 - 2010	30.4	27.7	29.9	31.1	28.3	32.3	30.9	28.9	31.5	32.1	31.6
	1901 - 1940	30.2	27.6	29.8	30.9	28.1	32.1	30.7	28.7	31.4	32.0	31.5
	1941 - 1980	30.4	27.7	29.9	31.2	28.4	32.4	30.8	28.8	31.5	32.1	31.5
	1981 - 2010	30.6	27.8	30.0	31.3	28.5	32.5	31.3	29.2	31.9	32.4	31.9
Mean	1901 - 2010	25.5	22.3	23.9	26.0	23.7	27.0	26.2	24.5	27.0	27.3	27.6
	1901 - 1940	25.4	22.2	23.9	25.8	23.6	26.9	26.0	24.3	26.8	27.2	27.5
	1941 - 1980	25.4	22.1	23.8	26.0	23.7	27.0	26.1	24.4	26.9	27.3	27.5
	1981 - 2010	25.8	22.5	24.1	26.2	24.0	27.3	26.6	24.8	27.3	27.6	27.8
Minimum	1901 - 2010	20.7	16.9	18.0	20.9	19.2	21.8	21.6	20.2	22.5	22.6	23.6
	1901 - 1940	20.6	17.0	18.0	20.8	19.1	21.7	21.4	20.0	22.4	22.5	23.6
	1941 - 1980	20.5	16.7	17.8	20.8	19.1	21.7	21.5	20.1	22.4	22.5	23.5
	1981 - 2010	21.0	17.3	18.2	21.1	19.5	22.2	21.9	20.5	22.7	22.9	23.8

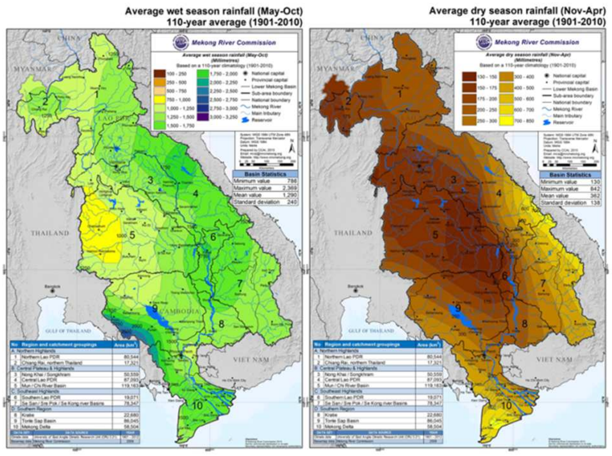
Figure 2.4: Average mean annual temperature and average maximum and minimum temperatures in the Lower Mekong Basin from 1901 to 2010 (MRC, 2015b).

Average annual rainfall across the LMB ranges from a minimum of 1,291 mm per year in the Mun/Chi river basin to a maximum of 1,992 mm per year in the Mekong delta, over the period 1901-2010 (Figure 2.5). These values are calculated by averaging rainfall across each sub-area. When considering localised rainfall maxima, the variability is much larger. Rainfall quantities as low as 1,000 mm per year are observed in northeast Thailand, whilst more than 3,000 mm per year is received close to the Gulf of Thailand.

Wet season rainfall contributes approximately 80% of the average annual rainfall budget. It therefore shows a similar spatial pattern to that of annual rainfall. Dry season rainfall exhibits limited spatial variability across the LMB, with a basin-wide average accumulation of 362 mm over the period of record.

Largest accumulations are again constrained to mountainous and coastal regions, with the Delta receiving an average of 463 mm per year.





Summary statistics of average rainfall for whole LMB and each sub-area (mm.)

	Time period	Average LMB	Average per sub-area, catchment groupings									
			1	2	3	4	5	6	7	8	9	10
Dry season	1901 - 2010	362	342	316	358	414	312	339	374	306	357	463
	1901 - 1940	341	319	282	332	386	293	311	358	294	332	465
	1941 - 1980	376	345	338	375	432	327	353	387	318	372	478
	1981 - 2010	371	367	334	369	428	316	359	379	307	371	442
Annual	1901 - 2010	1,652	1,479	1,425	1,525	1,854	1,291	1,900	1,925	1,699	1,696	1,992
	1901 - 1940	1,584	1,474	1,365	1,443	1,781	1,241	1,801	1,851	1,634	1,574	1,919
	1941 - 1980	1,683	1,468	1,485	1,564	1,879	1,329	1,933	1,918	1,720	1,766	2,052
	1981 - 2010	1,703	1,499	1,425	1,581	1,919	1,307	1,989	2,032	1,756	1,764	2,008
Wet season	1901 - 2010	1,290	1,136	1,108	1,167	1,439	979	1,561	1,549	1,392	1,338	1,527
	1901 - 1940	1,243	1,155	1,082	1,111	1,395	948	1,490	1,492	1,340	1,242	1,452
	1941 - 1980	1,307	1,122	1,147	1,189	1,446	1,002	1,580	1,531	1,402	1,394	1,576
	1981 - 2010	1,331	1,131	1,092	1,212	1,490	991	1,630	1,651	1,449	1,392	1,562

Figure 2.5: Average annual rainfall and average wet season and dry season rainfall in the Lower Mekong Basin from 1901 to 2010 (MRC, 2015b).

2.2.2 Historical changes in temperatures

A linear regression analysis (Figure 2.5) suggests that average mean temperatures have increased only moderately over the period of record (0.05˚C per decade), with negligible increases between 1901 and 1980. A strong increasing trend is, however, observed during the most recent period since 1981 (0.22˚C per decade). Such changes are in-line with global mean temperature increases reported in the IPCC's fifth assessment report (IPCC, 2014). Nearly identical trends are seen in both average maximum and average minimum temperatures, although it is of note that average maximum temperatures actually declined at a rate of 0.13˚C per decade between 1941 and 1980, with similar decreases being observed in each sub-area of the Basin. Since 1981, both average minimum and average maximum temperatures have increased at a rate equivalent to average mean temperatures. Unlike rainfall, temperature trends are very consistent between sub-areas, demonstrating that temperature changes are driven by larger scale atmospheric dynamics, whilst rainfall is often more locally controlled.

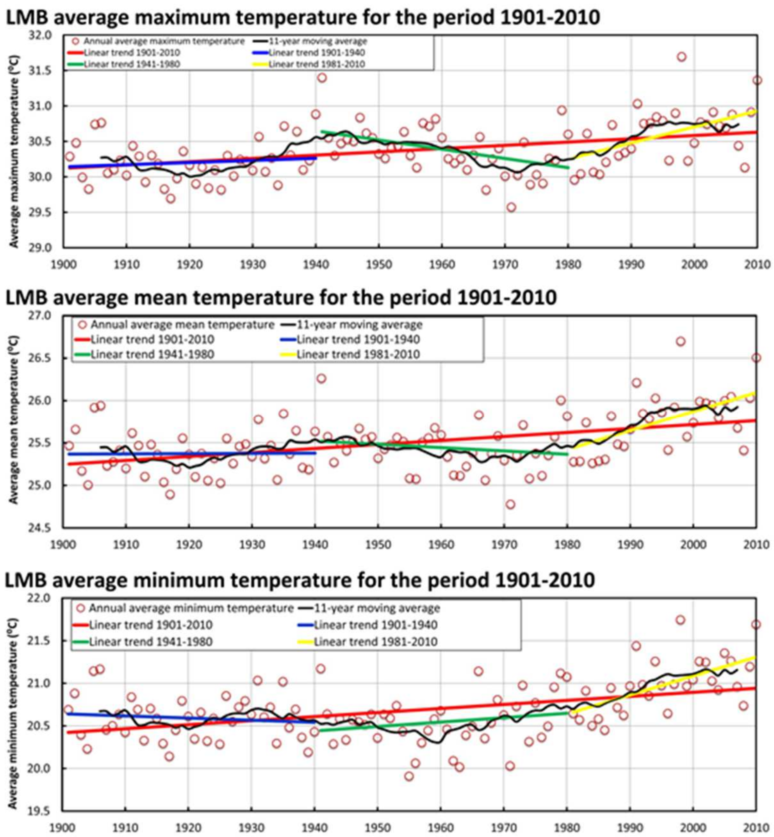


Figure 2.5: Trend in average maximum, mean and minimum temperatures across the Lower Mekong Basin for the period 1901-2010 (MRC, 2015b).

2.2.3 Changes in rainfall patterns

A linear regression analysis (Figure 2.6) suggests that most parts of the LMB show increases in rainfall over the period 1901-2010, with the largest annual increases observed in the Tonle Sap and Southeast Highlands (+20 to +50 mm per decade)(Figure 2.7). Similar trends are seen in the wet season, although it is noteworthy that increases in the Southeast Highlands are driven principally by enhanced dry season rainfall. Elsewhere, dry season rainfall shows only small positive increases (less than +10 mm per decade). In both seasons, a general drying is observed across the southernmost part of the delta.

Whilst the trend over the period 1901-2010 shows generally increasing rainfall in all seasons, the inter-decadal signal is less clear. Periods of below and above average rainfall throughout the record are apparent. The period 1901 to 1940 is characterized by strongly decreasing rainfall accumulations in all seasons, whilst the period 1941 to 1980 shows near-stationary trends. The most recent period, 1981 to 2010, exhibits large increases in the annual rainfall budget (+43 mm per decade), but most of this increase is constrained to the dry season (with an average increase of +36 mm per decade). Wet season increases are comparatively small on average (+6 mm per decade), principally driven by a strong drying trend across the Southern Region. Conversely, between 1955 and 2005, the ratio of rainfall in the wet to the dry seasons was shown by Aldrian and Djamil (2008) to have increased. Changes to monsoon onset and duration can also modify the trends that are observed within each season. Detection of changes to rainfall variability therefore remains a significant challenge (Turner and Annamalai, 2012).

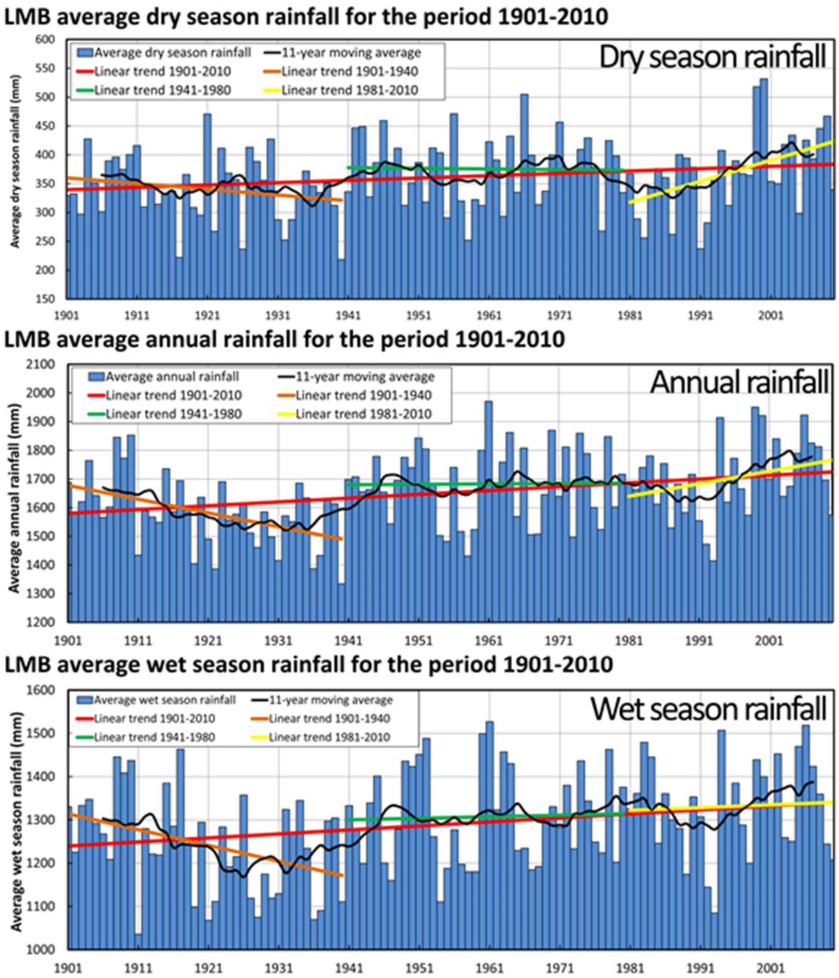


Figure 2.6: Trend in average dry season, annual and wet season rainfall across the Lower Mekong Basin for the period 1901-2010 (MRC, 2015b).

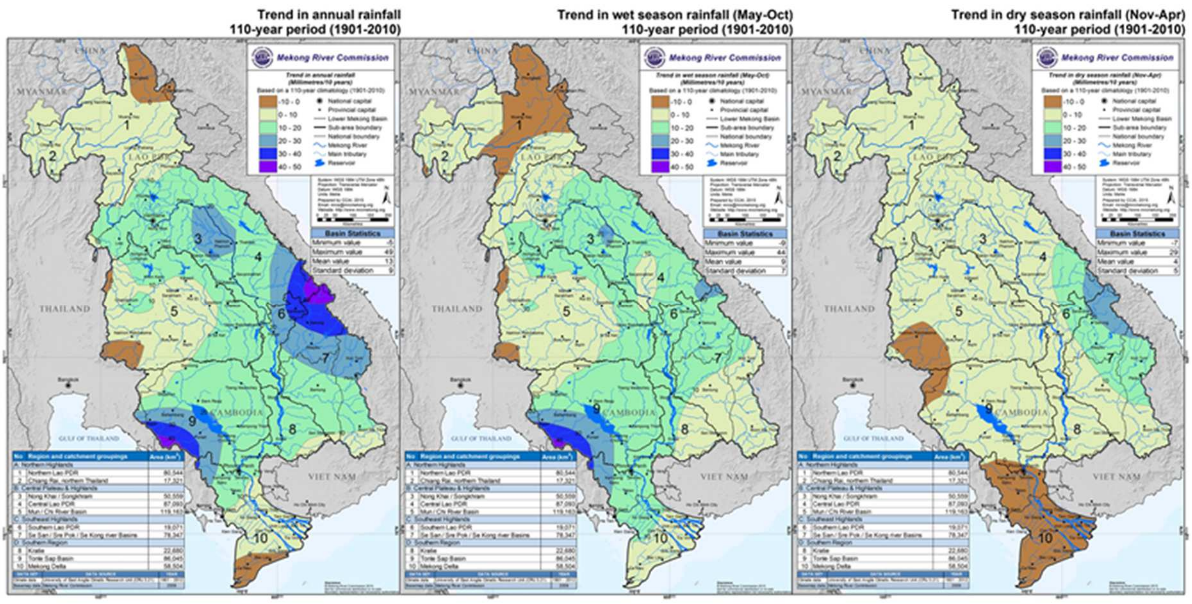


Figure 2.7: Geographic trends in the average annual, wet season and dry season rainfall across the Lower Mekong Basin for the period 1901-2010 (MRC, 2015b).

2.2.4 Occurrence of extremes

Changes to extremes have a disproportionate effect on society and ecosystems (IPCC, 2014). Understanding how extremes in climatic variables and events are changing is therefore of paramount importance. MRC (2016d) considers the change in occurrence of extreme events in the LMB by examining both the incidence of storm days (days with greater than 25 mm rainfall) and the change in the number of tropical storms and typhoons.

Significant daily storm rainfall depths are usually the result of more intense monsoonal conditions and tropical low pressure systems such as deep depressions and typhoons. The number of such "storm days" during the season appears to be reasonably consistent throughout most of the region (MRC, 2016d).

If a "storm day" is arbitrarily defined as one upon which more than 25mm of rainfall is recorded, a "significant storm day" as one upon which more than 50 mm occurs and an "extreme storm day" as one upon which more than 75 mm occurs, then the average annual count of these days is between 20 and 25, less than 10 and less than 5 respectively (Table 2.1).

Table 2.1: The mean annual number of storm days (>25mm), significant storm days (>50mm) and extreme storm days (>75mm) at Vientiane (1949 to 2013) and Pakse (1961 to 2013) (MRC, 2015d).

	Mean annual number of storm days		
	>25mm	>50mm	>75mm
Vientiane	22	7	2
Pakse	26	9	4

Considering whether the incidence of such events has systematically increased over time as a consequence of climate change, the results in Figure 2.8 indicate that there is no evidence to suggest any long term change, at least so far as the data at Vientiane and Pakse are concerned (MRC, 2016d).

Such assessments are important, and obviously need to be expanded, since the case is usually made that climate change will lead to an increase in the frequency and intensity of "storm days" and that short and long term weather conditions will become more variable. The vast majority of climate change studies that have been undertaken, including those carried out within the Mekong region have tended to deal more or less exclusively with changes to mean annual and monthly rainfall. The pattern in terms of storm frequency and the potential impacts upon the onset, end and intensity of the Southwest Monsoon remain in the realm of qualitative conjecture (MRC, 2016d). Yet it is these aspects that are the major influence upon the hydrological response to potential climate change, rather than seasonal changes to average rainfall.

Tropical storms (hurricanes, cyclones, typhoons) have become symbolic of climate change (Mendelsohn *et al.*, 2009). As the climate changes, the frequency and intensity of such storms are expected to increase, especially in the North Atlantic and the North West Pacific (Emanuel *et al*. 2008). Storms and typhoons affecting Viet Nam before moving eastwards into the Basin have been responsible in the past for some of the most extreme and damaging floods, recent examples include 'Linda' in 1997, 'Xangsane' in 2006 and 'Ketsana' in 2009. Any increase in their severity and frequency is a cause for major concern, bearing in mind that the worst 10 per cent of storms currently cause 90 per cent of the damage (Mendelsohn *et al.*, 2009).

(a) Vientiane **(b) Pakse**

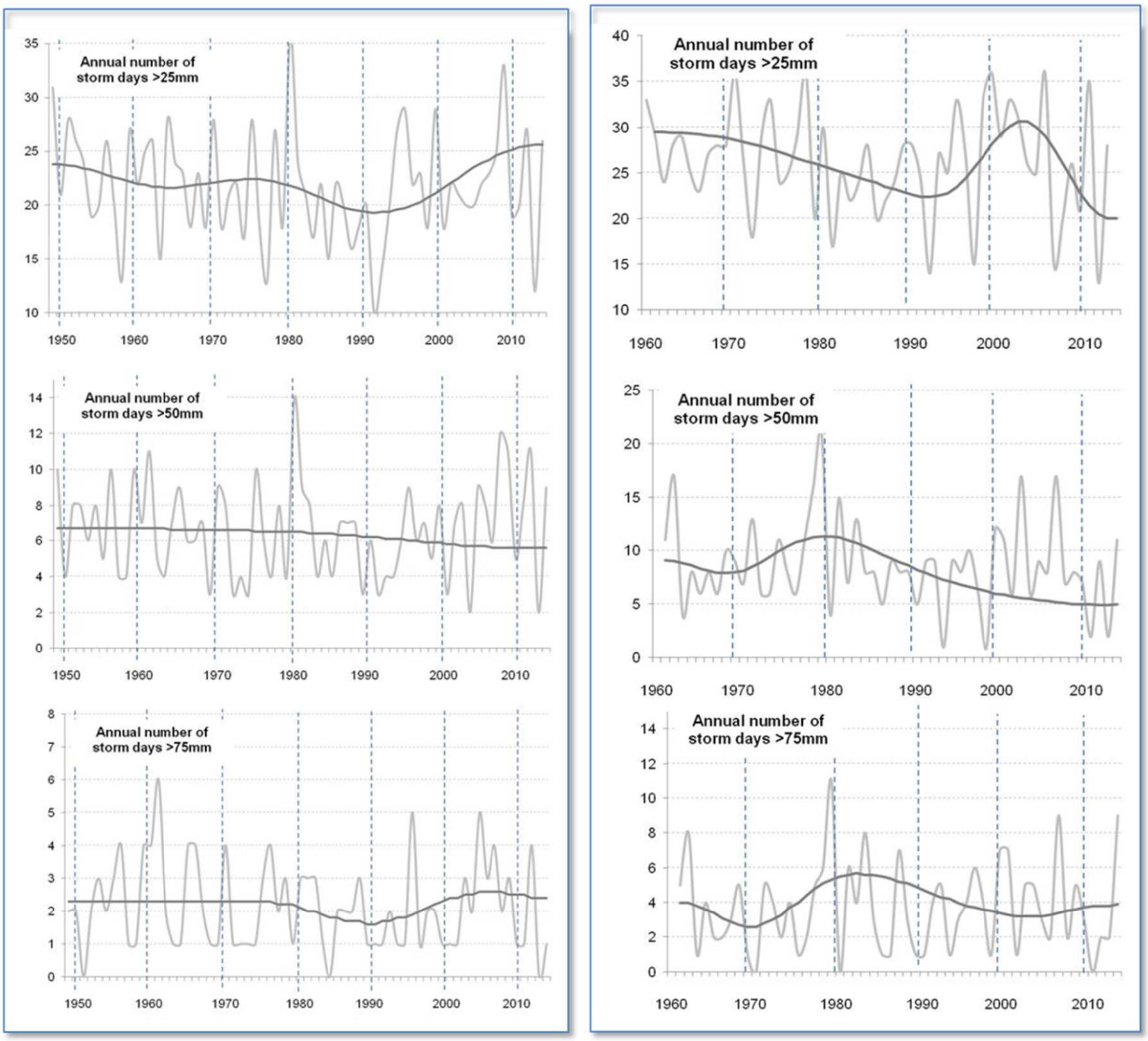


Figure 2.8: Annual number of storm days >25 mm, >50 mm and >75 mm with embedded trend at (a) Vientiane from 1949 to 2013 and (b) Pakse from 1961 to 2013 (MRC, 2015d).

There is no convincing statistical evidence to suggest that the frequency of typhoons and tropical storms is increasing. The data plotted in Figure 2.9 show the annual count of storms approaching Viet Nam from 1900 to-date, with a mean rate of 6.9 events per year. Imamura and To (1997) reviewed the post 1950 data from a different source and also concluded that the expected increase due to climate change was not historically evident. The same conclusion is drawn by Wu *et al*. (2006) in a study of trends in cyclone intensity in the western Pacific as a whole between 1965 and 2004. MRC (2017x) found no statistically significant trend in the number of storms of any category but did demonstrate a statistically significant decrease in storm intensity and accumulated cyclone energy from 1950 to 2010. MRC (2017x) also found statistically significant step changes in both the number and intensity of storms in 1963 and 1998.

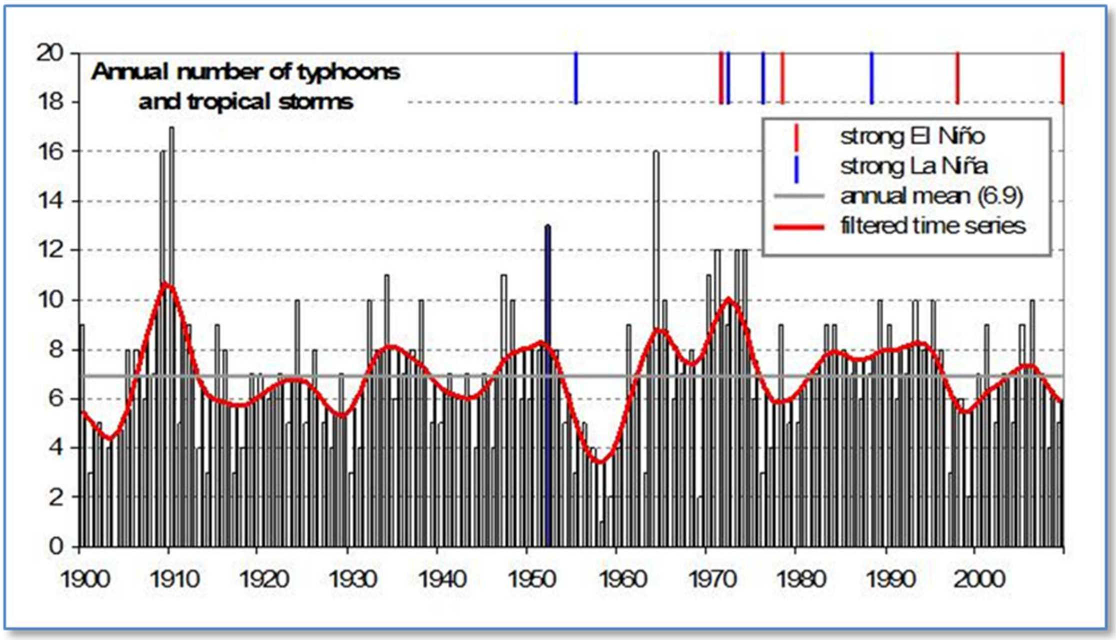


Figure 2.9: The number of tropical storms (wind speed > 57 km/h) and typhoons (wind speed > 118 km/h) approaching the coast of Viet Nam (specifically entering the latitude 7.50 to 22.50 N and longitude 105.00 to 115.00 E)[2] (MRC, 2015d).

Further confirmation that there has to-date been no systematic increase in typhoon genesis in the North-west Pacific and South China Sea / East Sea is available from the Japanese Meteorological Agency (JMA, 2012). The regional annual count data of significant and extreme tropical low pressure systems are available from 1951 to 2012. These are plotted in Figure 2.10 and illustrate that there is no evidence that the incidence of such events has increased over the last 63 years. Indeed, since 1998 the incidence of regional storms is considerably less than the long-term average.

Although the regional count of tropical storms shows no impact so far of climate change influences, arguments have been advanced in recent years that the intensity of storms may be increasing, particularly in the aftermath of super typhoon Haiyan which struck the central Philippines in 2013. This was the most intense tropical system to make landfall since authoritative records began, with wind speeds as high as 310 km/h. However, an analysis of trends in intense tropical cyclones in East Asia between 1977 and 2010 showed only a weak increasing trend with the location of maximum intensity closer to the Viet Nam coast (Park *et al.,* 2014) but no significant change in landfall intensity across Viet Nam.

[2] The data from 1900 to 1995 are drawn from the CD-Rom Global Tropical and Extra-Tropical Cyclone Atlas, Version 2, US Navy, Department of Commerce, Washington DC. 1996. (see Adger *et al*., 2001). The post 1995 data to 2009 are drawn from Giang (2005) and the MRC Annual Flood Reports. The El Niño/La Niño information is taken from the 'consensus data' available from 1950 onwards at http://ggweather.com/enso/years.htm

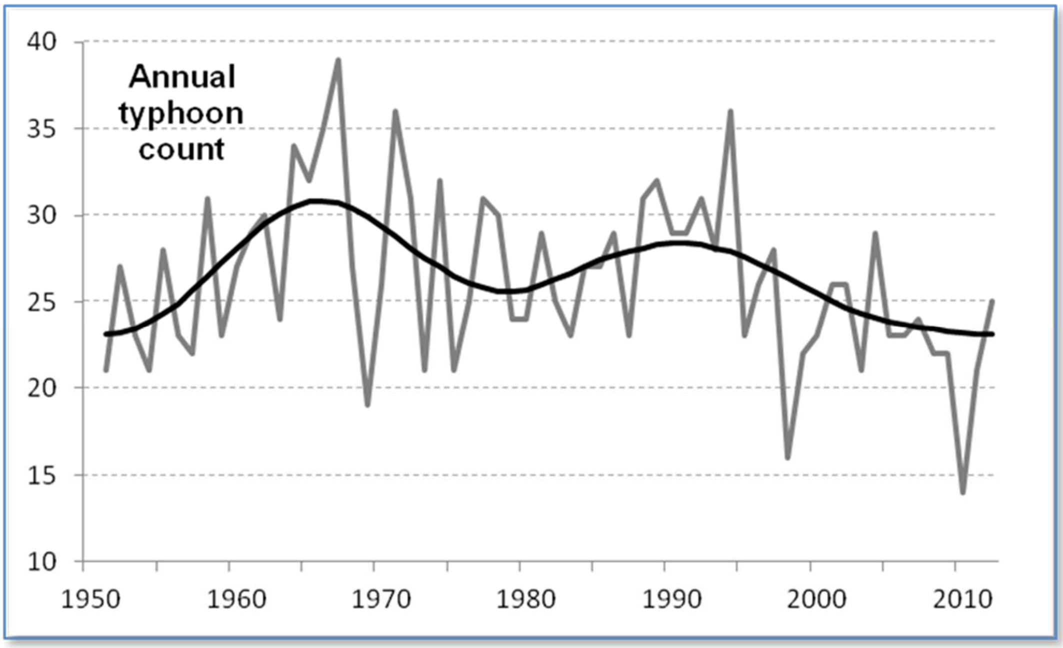


Figure 2.10: The annual count (1951 to 2012) of tropical storm and typhoon genesis in the NW Pacific and the South China Sea / East Sea. The smooth function is the embedded residual trend. The mean annual rate of regional system formation is 26.6 events per year (MRC, 2015d; *Source: JMA (2012)).*

2.2.5 Greenhouse gas emissions from Lower Mekong Basin countries

As identified in IPCC (2014) increasing concentrations of anthropogenic greenhouse gases in the atmosphere are highly likely to be the cause of global warming since the mid-20th century. Greenhouse gas emissions of MRC Member Countries make a very small contribution to overall global emissions. Emissions data has been assessed through the CAIT Climate Data Explorer website[3], which draws upon the resources of the Analysis Centre[4] for carbon dioxide information, Food and Agriculture Organization of the United Nations (FAO)[5] for data for land-use and forestry information, International Energy Agency (IEA)[6] for CO_2 emissions from fuel combustion as well as from the World Bank[7], US Energy Information Administration (EIA)[8] and the US Environmental Protection Agency (EPA)[9]. The trends in each country derived from CAIT resources are illustrated in Figure 2.11 for each country (note that data are for the entire country, not for that part covering the LMB).

3 CAIT Climate Data Explorer. 2015. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org

4 Carbon Dioxide Information - Analysis Center - Boden, T.A., G. Marland, and R.J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2015 Available online at:http://cdiac.ornl.gov/trends/emis/overview_2011.html .

5 Food and Agriculture Organization of the United Nations (FAO). 2014. FAOSTAT Emissions Database. Rome, Italy: FAO. Available at: http://faostat3.fao.org/download/G1/*/E

6 International Energy Agency (IEA). 2014. CO2 Emissions from Fuel Combustion (2014 edition). Paris, France: OECD/IEA. Available online at: http://data.iea.org/ieastore/statslisting.asp. © OECD/IEA, [2014].

7 World Development Indicators 2014. Washington, DC. Available at: http://data.worldbank.org/ Last Accessed May 18th, 2015

8 US Energy Information Administration (EIA). 2014. International Energy Statistics Washington, DC: U.S. Department of Energy. Available online at:http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8

9 US Environmental Protection Agency (EPA). 2012. “Global Non-CO2 GHG Emissions: 1990-2030.” Washington, DC: EPA. Available at: http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html.

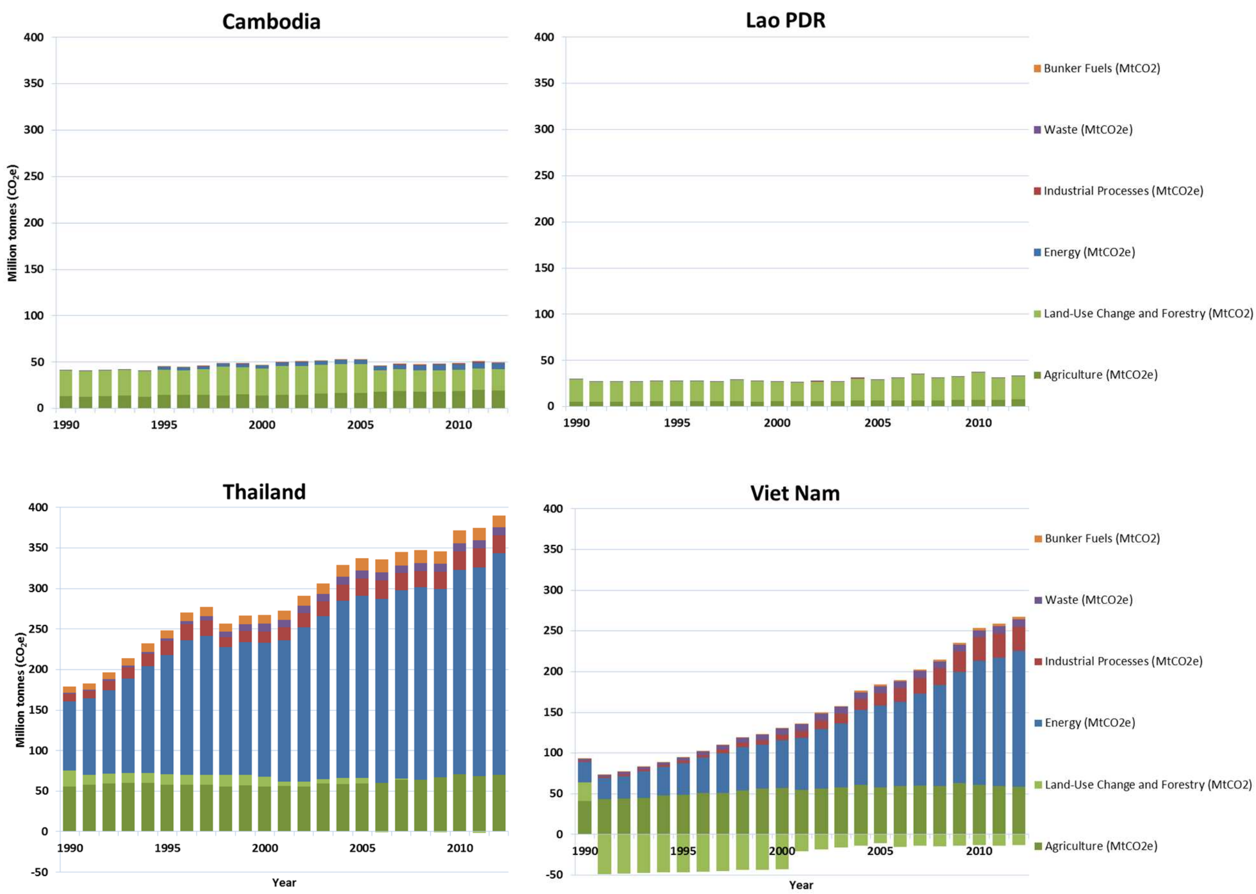


Figure 2.11: Greenhouse gas emissions by sector and whole country (MRC, 2016a; *Source: CAIT Climate Data Explorer website*).

Figure 2.11 shows that the majority of greenhouse gas emissions are occurring in the energy sector, and that the energy sectors in Thailand and Viet Nam are much greater than Cambodia and Lao PDR as a result of higher national populations and larger industrial sectors.

Each Member Country has identified in its National Communications to the United Nations Framework Convention on Climate Change[10] some of the options it is taking or will seek to take, to mitigate and reduce emissions from the relevant baseline scenario. For example, Cambodia in its most recent communication (2015) identified emissions savings (in CO_2-eq) of approximately 26 per cent (from Business-as-Usual emissions from 2025 onwards) with about 60 per cent of that realized in the energy sector as a result of increasing energy efficiency measures. Lao PDR has identified mitigation options across a range of sectors; for example, in waste management options that could reduce methane emissions by approximately 31,000 Gg by 2030. Thailand and Viet Nam have similarly undertaken or identified options in sectors including energy, agriculture and land-use change and forestry. Under the recent Paris Agreement[11] each Party will identify every five years its nationally determined contribution to reducing emissions. The first of these is to be submitted no later than when the Party submits its respective instrument of ratification, acceptance approval or accession to the Agreement.

[10] http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php

[11] http://unfccc.int/meetings/paris_nov_2015/items/9445.php

Emissions of Carbon Dioxide have been rising for all Member Countries except Cambodia with the increase particularly significant for Thailand and Viet Nam. Emissions of Nitrous Oxide and Methane have also been rising across all four Member Countries, at a higher rate of change than for CO_2 for Cambodia and Lao PDR, but a lower rate of change for Thailand and Viet Nam (Figure 2.12). Total emissions per capita from all greenhouse gases have been falling in Cambodia and Lao PDR and rising in Thailand and Viet Nam.

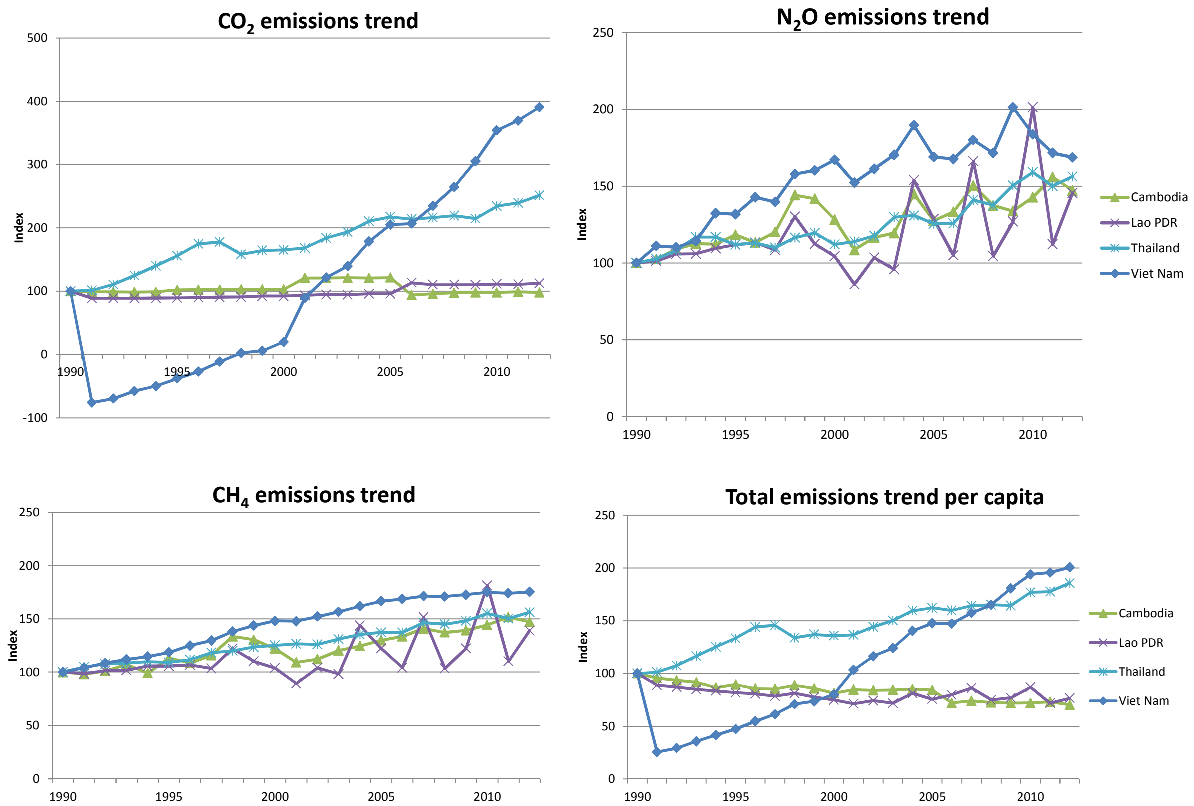


Figure 2.12: Trend in greenhouse gas emissions by gas (CO_2, CH_4, N_2O) and total emissions per capita (1990 baseline = 100) [12] (MRC, 2016a; *Source: CAIT Climate Data Explorer website)*

[12] CAIT Climate Data Explorer. 2015. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org. Change in emissions based on CO_2 equivalents for each gas.

2.3 Global Climate Change Projections

2.3.1 Global temperature and precipitation projections

At a global level, surface temperature is projected to rise over the 21st century under all assessed emissions scenarios (IPCC, 2014). It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea-level will rise (IPCC, 2014).

Future projections depend both on committed warming caused by past anthropogenic emissions already in the atmosphere and well as future emissions and natural climate variability. Under all four emissions scenarios used for the IPCC's fifth assessment report the projected temperature increase over the period 2016-2035 is similar and in the range 0.3˚C to 0.7˚C (Figure 2.13). Longer term changes are affected by the choice of emissions scenario although there is still a high likelihood of exceeding a 1.5˚C rise in global temperature by 2100 for all scenarios and a high likelihood of a greater than 2˚C rise for the RCP6.0 and RCP8.5 scenarios (IPCC, 2014) The mean increase to 2046-2065 is between 1-2˚C. It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperatures increase (IPCC, 2014).

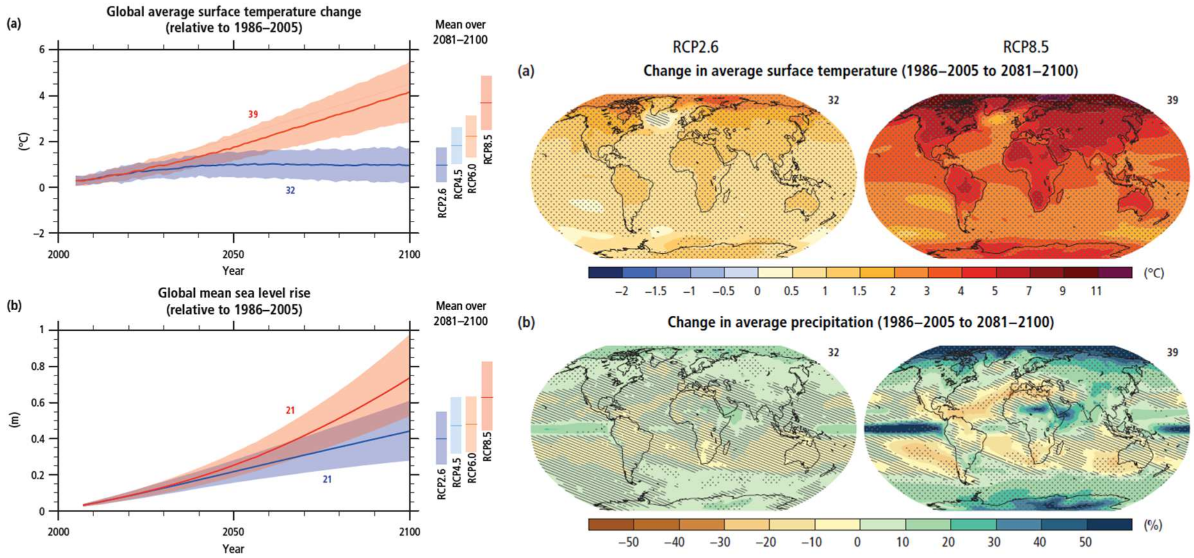


Figure 2.13: Projected average changes in global surface temperature, mean sea-level rise and change in average precipitation (IPCC, 2014).

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are likely to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will likely decrease, while in many mid-latitude wet regions, mean precipitation is likely to increase under the RCP8.5 scenario. Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent (IPCC, 2014). The fifth assessment report also projects likely increases in global ocean temperatures with an increase in ocean acidification, year-round reductions in Arctic sea ice, a reduction in near-surface permafrost extent at high northern latitudes and a reduction in global glacier volume by 15 to 55 per cent for RCP2.6 and by 35 to 85 per cent for RCP8.5. Global mean sea level rise will continue during the 21st century, very likely at a faster rate than observed from 1971 to 2010. The increase is likely to be in the range of 0.26 to 0.55m for RCP2.6 and from 0.45 to 0.82m for RCP8.5. Sea level rise will not be uniform across the globe. About 70 per cent of the coastlines worldwide are projected to experience a sea level change within ±20 per cent of the global mean (IPCC, 2014).

2.4 Regional Climate Change Projections

Regional projections of changes in temperature and rainfall are largely consistent with global projections. That is, increasing temperatures and either increasing or decreasing rainfall depending on regional factors at range of scales. The rate of projected increase in temperatures is, however, much greater at the regional level than at the global level, with the upper range of increases from 3°C to 4°C by 2060, similar to global projections for 2090. The Lower Mekong Basin is projected to warm at a greater rate than the average global increase under all scenarios examined.

As expected, greater increases in mean annual temperature occur with higher resource concentration pathways (Table 2.2). The average mean annual temperature across the LMB by 2060 is 25.5°C under RCP2.6, 26.5°C-26.6°C under RCP 4.5 and 27.9°C-28.1°C under RCP 8.5. Mean annual temperatures are generally higher in 2060 than in 2030 except for RCP2.6 where they are not projected to increase much, if at all, beyond 2030.

Table 2.2: Overview of basic climatic variables averaged across the Lower Mekong Basin projected for the years 2030 and 2060 for each resource concentration pathway (RCP 2.6; 4.5; 8.5) and each scenario (wetter overall, drier overall, increased seasonality) (MRC, 2017a; *Source: Zomer (2016)).*

Scenario / RCP		Mean Annual Temperature		Annual Precipitation		PET		AWI	
		° C		mm		mm			
	Year:	2030	2060	2030	2060	2030	2060	2030	2060
Wetter									
(gf)	RCP 2.6	25.6	25.5	1753	1743	1622	1618	1.09	1.09
	RCP 4.5	26.0	26.6	1783	1837	1635	1658	1.10	1.12
	RCP 8.5	26.5	28.1	1832	1971	1656	1715	1.12	1.16
Drier									
(gs)	RCP 2.6	25.6	25.5	1672	1681	1623	1619	1.04	1.05
	RCP 4.5	26.0	26.6	1641	1588	1638	1663	1.02	0.97
	RCP 8.5	26.5	28.1	1592	1454	1661	1726	0.97	0.86
Seasonal									
(ip)	RCP 2.6	25.6	25.5	1739	1733	1629	1623	1.08	1.08
	RCP 4.5	25.9	26.5	1760	1796	1648	1680	1.08	1.08
	RCP 8.5	26.4	27.9	1793	1886	1678	1763	1.08	1.08
Ensemble									
	RCP 2.6	25.6	25.5	1742	1735	1621	1617	1.09	1.09
	RCP 4.5	26.0	26.5	1765	1805	1634	1656	1.09	1.10
	RCP 8.5	26.5	28.0	1802	1905	1655	1712	1.10	1.13

The direction of change in precipitation is determined by the choice of model, with both the overall wetter and increased seasonality models projecting a wetter LMB on average, while the drier overall model projects a drier LMB on average (Table 2.2). Again, the magnitude of change is affected by the resource concentration pathway – the higher the RCP the greater the change. This is a similar result for Available Water Index (AWI). Average potential evapotranspiration (PET) across the Basin increases under all scenarios and all models.

2.4.1 Changes in Temperature

The change in annual, dry season and wet season average basin-wide temperature for the selected scenarios is summarized in Table 2.3. These results indicate that:

- The change in annual average temperature is projected to vary within a range of +0.4°C to +3.3°C by 2060 (+0.5°C to +1.5°C by 2030);
- The change in dry season average temperature is projected to vary within a range of +0.3°C to +3.3°C by 2060 (+0.5°C to +1.5°C by 2030); and
- The change in wet season average temperature is projected to vary within a range of +0.4°C to +3.4°C by 2060 (+0.5°C to +1.6°C by 2030).

Essentially, increases in monthly temperatures are highly consistent across the year and across climate models with variations strongly linked to emissions scenarios (MRC, 2016c); the higher the emissions scenario, the greater the magnitude of projected temperature changes. The direction of change is one of increasing average temperature across both wet and dry seasons in all models and scenarios.

Table 2.3: Summary of projected basin-wide changes in (a) annual; (b) dry season; and (c) wet season basin-wide temperatures to 2030 and 2060 under three RCPs (2.6; 4.5; 8.5) and three model scenarios (drier overall, wetter overall, increased seasonality) (MRC, 2016c).

Annual	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	0.5	0.4	0.9	1.6	1.5	3.3
Increased seasonal variability	0.5	0.4	0.9	1.5	1.5	3.1
Wetter overall	0.5	0.4	0.8	1.5	1.4	3.1

Dry season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	0.5	0.4	0.9	1.6	1.5	3.3
Increased seasonal variability	0.5	0.3	0.8	1.4	1.3	2.8
Wetter overall	0.5	0.4	0.8	1.5	1.4	3.1

Wet season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	0.5	0.4	0.9	1.6	1.5	3.3
Increased seasonal variability	0.5	0.4	0.9	1.6	1.6	3.4
Wetter overall	0.5	0.4	0.8	1.5	1.4	3.0

The direction of change in mean annual temperature across the LMB is consistent with previous modelling undertaken through a range of other studies (Table 2.6). The magnitude of that increase varies based on the model used, the emissions scenario selected, the baseline period, the projected timeframes examined, and other methodological choices. Nevertheless, the temperature increases reported are generally within the envelope of increases documented above through the MRC's basin-wide assessment work using the most recent suite of SimCLIM models and the guidance on emissions scenarios and baseline period provided by the IPCC.

The spatial variation in temperature increases generally shows greater increases in the north of the basin than the south (MRC, 2015b; 2016c) with some higher temperatures extending across much of the Khorat plateau under both the wetter and drier overall scenarios. Maximum increases in mean annual temperature are typically constrained to northern and western parts of the LMB, while the Delta region exhibits the smallest increases (Figure 2.14). The drier overall model highlights a particularly strong warming trend in the Mun/Chi River Basin, with a relatively strong west to east temperature gradient. The smallest increases are anticipated in the east of the basin. The wetter overall and increased seasonality models are instead oriented from north to south, with the smallest increases in the south.

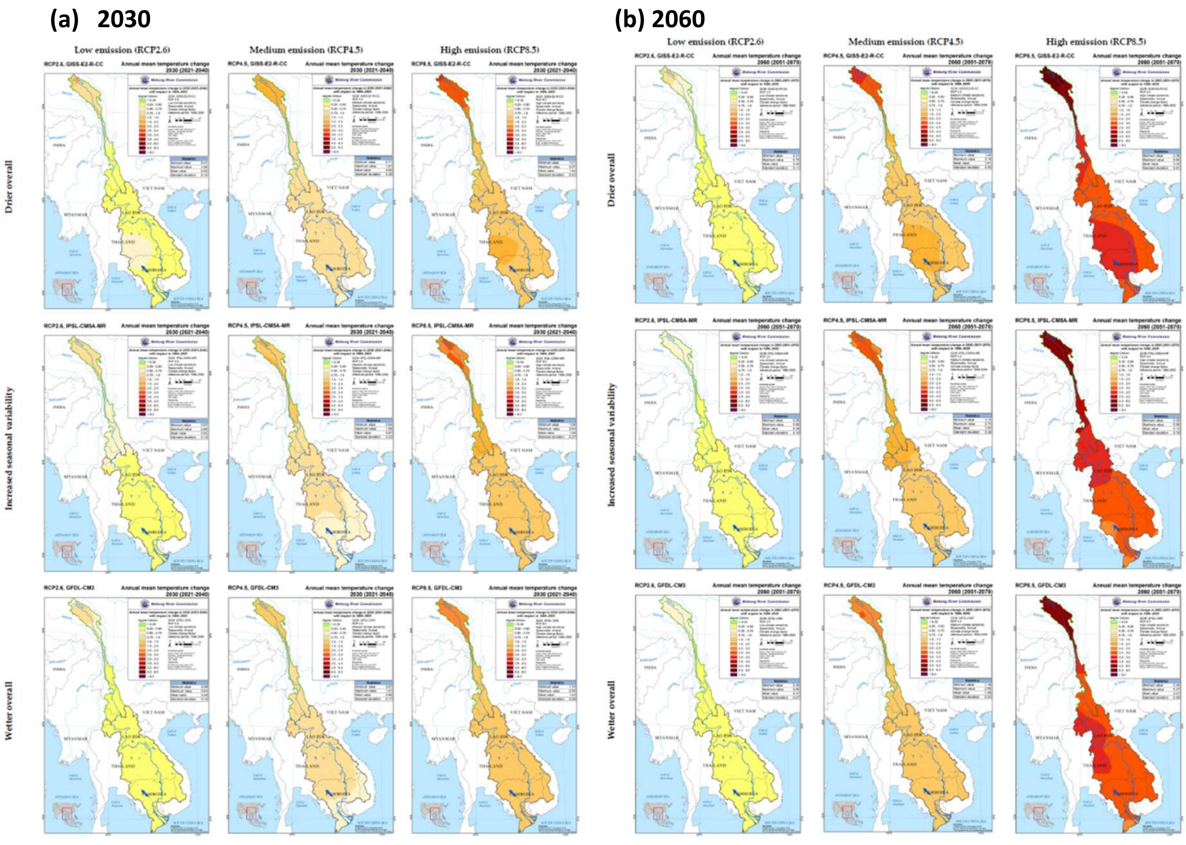


Figure 2.14: Spatial variations in annual average mean temperature changes projected to (a) 2030 and (b) 2060 under three emissions scenarios (RCP2.5; RCP4.5; RCP8.5) and three model scenarios (wetter overall, drier overall, increased seasonality) (MRC, 2016c).

Averaged across the entire LMB, maximum temperature increases are identical in magnitude to mean increases (MRC, 2016b). Broader areas of warming are, however, evident in all scenarios particularly in central and northern areas. Minimum temperature increases are smaller in magnitude than average and maximum temperature increases, although only by 0.1°C to 0.3°C.

2.4.2 Changes in rainfall

The change in annual, dry season and wet season average basin-wide rainfall for the selected scenarios is summarized in Table 2.4. These results indicate that:

- The change in annual rainfall is projected to vary within a range of -16% to +17% by 2060 (-7% to +8% by 2030);
- The change in dry season rainfall is projected to vary within a range of -23% to +23% by 2060 (-11% to +11% by 2030); and
- The change in wet season rainfall is projected to vary within a range of -18% to +16% by 2060 (-8% to +8% by 2030).

Essentially, projected changes in monthly rainfall are highly inconsistent across the year and across scenarios but with the magnitude of change strongly linked to the choice of emissions scenario (MRC, 2016c); other than for dry season changes in the drier overall model, the higher the emissions scenario the greater the magnitude of projected rainfall change whether that change involves a reduction or an increase in rainfall (Table 2.4).

Table 2.4: Summary of projected changes in annual, dry season and wet season basin-wide rainfall to 2030 and 2060 under three RCPs (2.6; 4.5; 8.5) and three model scenarios (drier overall, wetter overall, increased seasonality) (MRC, 2016c).

Annual	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	-2%	-2%	-4%	-8%	-7%	-16%
Increased seasonal variability	2%	2%	3%	5%	5%	10%
Wetter overall	3%	2%	5%	8%	8%	17%

Dry season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	0%	0%	-1%	-1%	-1%	-1%
Increased seasonal variability	-4%	-3%	-7%	-11%	-11%	-23%
Wetter overall	3%	3%	6%	11%	11%	23%

Wet season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	-3%	-2%	-5%	-9%	-8%	-18%
Increased seasonal variability	3%	2%	5%	8%	8%	15%
Wetter overall	3%	2%	5%	8%	8%	16%

As described in MRC (2016c) the variations in projected rainfall change tend to be greatest during the peaks of the dry season (March: -60% to +71% by 2060) and wet season (October: -33% to +92% by 2060). The greatest reductions in projected rainfall tend to occur during the January to March/April period, associated with the drier overall and increased seasonality scenarios, while the greatest increases in projected rainfall tend to occur in the September to December period for the increased seasonal variability scenario, and in March and August to November for the wetter overall scenario. There is a distinctive change in the pattern of projected change in rainfall across the three scenarios and a distinctive change in magnitude of projected change in rainfall across the three emission scenarios. In summary:

- the drier overall scenario tends to show reductions in rainfall;
- the increased seasonal variability scenario tends to show reductions in rainfall during the period January to June and increases in rainfall during the period July to December;
- the wetter overall scenario tends to show increases in rainfall; and
- the magnitude of change increases from the low emission (RCP2.6) through to high emission (RCP8.5) scenarios.

These results are broadly consistent with the results of previous modelling undertaken through a range of other studies (Table 2.6). An increase or a decrease in mean annual rainfall is a plausible future outcome. There is also a wide range of possible variations in the magnitude of change such that it is not possible to be confident about either the direction or magnitude of future changes in basin-wide rainfall across the LMB.

Projected changes to annual precipitation accumulations show considerable spatial variability between model simulations (Figure 2.15). The drier overall model shows a greater reduction in the northern LMB over northern Lao PDR and over the central LMB in Thailand and Cambodia. Some areas on the periphery of the LMB under the drier overall model become wetter, for example in the headwaters of the 3S sub-basin at the intersection of Cambodia, Lao PDR and Viet Nam. The increased seasonal variability model projects a wetter north and central LMB over Lao PDR and Thailand and a drier southern zone in Cambodia and Viet Nam, while the wetter overall model produces a west to east rainfall gradient with higher rainfall projected in the west, particularly under the high emissions scenario.

Wet and dry season changes also exhibit considerable variability between model simulations. Projections derived from drier overall model suggest a drying in the wet season and insignificant increases in the dry season (MRC, 2015b). Projections derived from the wetter overall model suggest a wetting in both seasons. The increased seasonality model shows a wetter wet season and drier dry season, therefore suggesting that rainfall maxima and minima will be amplified.

In models where a drying trend is observed, the largest changes are typically constrained to inland areas, particularly in the Central Plateau and Highlands. Wet season changes show similar spatial patterns of change to annual changes, whilst dry season changes are very different. Across all models, changes to wet and dry season precipitation are typically smallest in the Delta region.

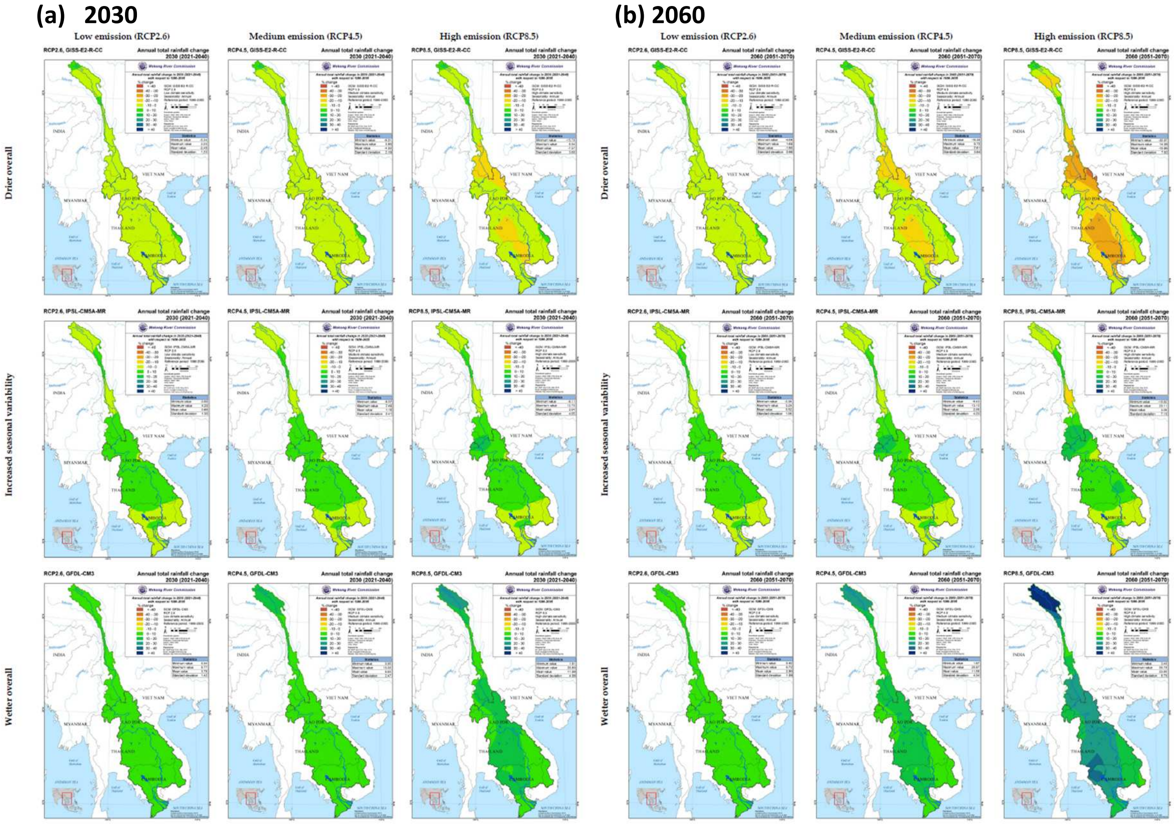


Figure 2.15: Spatial variations in annual average mean rainfall changes projected to (a) 2030 and (b) 2060 under three emissions scenarios (RCP2.5; RCP4.5; RCP8.5) and three model scenarios (wetter overall, drier overall, increased seasonality) (MRC, 2016c).

2.4.3 Changes in Potential Evapotranspiration (PET)

The change in annual, dry season and wet season average basin-wide Potential Evapotranspiration (PET) for the selected scenarios is summarized in Table 2.5. These results indicate that:

- The change in annual PET is projected to vary within a range of -5% to +20% by 2060 (+1% to +7% by 2030);
- The change in dry season PET is projected to vary within a range of -8% to +21% by 2060 (+1% to +6% by 2030); and
- The change in wet season PET is projected to vary within a range of -3% to +19% by 2060 (+2% to +8% by 2030).

According to MRC (2016c) the variation in change is primarily associated with the choice of emissions scenario, although some variation is also associated with the model scenario such that the increases seasonal variability scenario shows greater variation in projected PET than the other two scenarios.

Across the range of climate scenarios, there is a relatively narrow range of projected change in monthly PET of -10% to +26% (by 2060). The variations in projected PET change tend to be greatest during the dry season (-8% to +21% by 2060) compared to the wet season (-3% to +19% by 2060), with the greatest reductions in the dry season associated with the low emissions scenario and the greatest increases also during the dry season but associated with the high emissions scenario.

Table 2.5: Summary of projected changes in annual, dry season and wet season potential evapotranspiration to 2030 and 2060 under three RCPs (2.6; 4.5; 8.5) and three model scenarios (drier overall, wetter overall, increased seasonality) (MRC, 2016c).

Annual	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	1%	1%	2%	4%	4%	8%
Increased seasonal variability	2%	-5%	4%	6%	6%	20%
Wetter overall	2%	2%	4%	2%	7%	14%

Dry season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	1%	1%	2%	3%	3%	7%
Increased seasonal variability	2%	-8%	4%	5%	6%	21%
Wetter overall	2%	2%	3%	2%	6%	13%

Wet season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	2%	1%	3%	5%	5%	10%
Increased seasonal variability	2%	-3%	4%	6%	6%	19%
Wetter overall	3%	2%	5%	3%	8%	16%

Table 2.6: Selected climate modelling results of previous studies for mean temperature, mean precipitation and hydrology for the Mekong Basin.

	MRC-CCAI 2014g	ICEM 2013	Hunag et al. 2014	Lauri et al. 2012	Laux et al. 2013	Kingston et al. 2011	Thompson et al. 2013	Thompson et al. 2013	Hoanh et al. 2010	TKK & SEA START 2009	Johnston et al. 2009	Eastham et al. 2008	Kiem et al. 2008	Chinvanno et al. 2006	Hoanh et al. 2003	Snidvongs et al. 2003
Region	LMB	LMB	Mekong Basin	Mekong Basin	GMS	Mekong Basin	Mekong Basin	Mekong Basin	Mekong Basin	LMB	GMS	Mekong Basin	Mekong Basin	LMB	LMB	LMB
GCM	GFDL-CM3, GISS-E2-R-CC, IPSL-CM5A-MR	ccma_cgcm3.1, cnrm_cm3, ncar_ccsm3_0, miroc3_2_hires, giss_aom, mpi_echam5	24 GCMs	CCCMA_CGCM3.1 CNRM_CM3 GISS_AOM MIROC3.2Hires MPI_ECHAM5 NCAR_CCSM3	ECHAM5	UKMO HadCM3 CCCMA CGCM31 CSIRO Mk30 IPSL CM4 MPI ECHAM5 NCAR CCSM30 UKMO HadGEM1	UKMO HadCM3 CCCMA CGCM31 CSIRO Mk30 IPSL CM4 MPI ECHAM5 NCAR CCSM30 UKMO HadGEM1	UKMO HadCM3	ECHAM4	ECHAM4	ECHAM4	11 GCMs	JMA AGCM	CCAM (RCM)	HadCM3	CCAM (RCM)
Downscaling method	SimCLIM	Statistical downscaling	-	Statistical downscaling	WRF (dynamical downscaling)	ClimGen (pattern-scaled downscaling)	ClimGen (pattern-scaled downscaling)	ClimGen (pattern-scaled downscaling)	PRECIS	PRECIS	PRECIS	Pattern-scaling	-	-	-	-
Hydrological model	-		-	Vmod	-	SLURP	MIKE SHE	MIKE SHE	SWAT, IQQM, ISIS	VIC, POM, DIVA, EIA 3D	-	Water account model	YHyM	-	SLURP	-
Scenario	RCP 6.5, 8.5	SRES A1B	RCP 2.6, 4.5 and 8.5	SRES A1B, B1	SRES A1B, B1	Prescribed global warming of +0.5-+6°C	Prescribed global warming of +2°C	Prescribed global warming of +1.0-+6°C	SRES A2, B2	SRES A2, B2	SRES A2, B2	SRES A1B	SRES A1B	540 ppm and 720 ppm	SRES A2, B2	700 ppm
Baseline period	1986-2005	1980 to 2005	1950 to 2005	1982-1992	1971-2000	1961-1990	1961-1990	1961-1990	1985-2000	1995 to 2004		1961-1990	1979-1998	360 ppm	1961-1990	350 ppm
Scenario period	2081-2100	2045 to 2069	until 2100	2032-2042	2001-2030 (I) 2021-2050 (II)	-	-	-	2010-2050	2010-2049	1960-2049	2030	2080-2099	540 ppm (I) 720 ppm (II)	2010-2039 (I) 2070-2099 (II)	700 ppm
Mean temperature	+1.9°C - +2.1°C (RCP6.0), +4.5°C - +4.9°C (RCP8.5)	average daily max. temperature: +1.6°C - +4.1°C (spatially differentiated multi-model mean)	0.88°C/100yrs (RCP 2.6), 2.15°C/100yrs (RCP 4.5), 4.96°C/100yrs (RCP 8.5) (multi-model mean)	+0.8-+1.4°C (A1B) +0.6-+1.3°C (B1)	+0.17°C (B1 I) +0.38°C (A1B I) +0.6°C (B1 II) +1.39°C (A1B II)	+0.5-+6°C (prescribed)	+2°C (prescribed)	+1.0-+6°C (prescribed)	+0.7°C (A2) +0.8°C (B2)	+2-+3°C (+1-+2°C from Västilä et al. 2010, Scenario A2 only)	+0.023°C/yr to +0.024°C/yr	+0.68-+0.81°C	+2.6°C	Slight decrease (I) and increase (II)	+1.0°C (B2 I) +1.0°C (A2 I) +2.9°C (B2 II) +4.0°C (A2 II)	increase in daily max. temperature by +1-+3°C from Jan. to May, decrease from Oct. to Dec.
Mean precipitation	-3.7% - +10.5% (RCP6.0), -25.9% - +24.9% (RCP8.5)	annual precipitation:+3 - +14% (spatially differentiated multi-model mean)	-	-2.5-+8.6% (A1B) +1.2-+5.8% (B1)	+90mm (B1 I) -5mm (A1B I) +74mm (B1 II) -20mm (A1B II)	only very slight changes, except for three northern basins, where increases occur, seasonal changes are very heterogeneous	heterogeneous changes reaching from -6.1-+12.3% for different sub-catchments	-2-+5% for different sub-catchments for 1°C-scenario; -6.9-+30.2% for different sub-catchments for 6°C-scenario	annual: +1.2mm/yr (B2) +2.0mm/yr (A2); wet season: +1.2mm/yr (B2) +1.5mm/yr (A2); dry season: +0.06mm/yr (B2) +0.54mm/yr (A2)	+4% (from Västilä et al. 2010, Scenario A2 only)	no significant change in mean annual precipitation, wetter wet season in North Myanmar and Gulf of Thailand, drier dry seasons around Gulf of Thailand	mean: +13.5% range of models: +0.5-+36.0%	+4.2%	mean annual precipitation increases from 0-+25% for different sub-catchments	-0.2% (B2 I) +0.2% (A2 I) +9.4% (B2 II) +9.8% (A2 II)	drier and longer dry seasons
Discharge	-	Chiang Saen to Kratie: flow volume increases, wet season duration increases	-	Kratie:-11-+15% in wet season, -10-+13% in dry season	-	Pakse: -5.4-+4.5% for annual runoff, -16-+55% in monthly discharge	8 gauges: -21.6-+16.5% for annual runoff	upstream gauges: increase with increasing temperature, central gauges: increases, downstream gauges: decrease with increasing temperature	several gauges: increase in annual, wet season and dry season discharge	Kratie: +4.3% for annual runoff, +5.1% for wet season, -2.2% for dry season	-	-8-+90% for different sub-catchments	+11.7% in mean annual discharge, -4.3-+24.5% changes in monthly dicharges	-	mean monthly discharge in the delta: constant (B2 I) constant (A2 I) +4% (B2 II) +14% (A2 II)	-

Chapter 3: Impact and vulnerability of natural resources

3.1 Water resources

Key findings

Over recent decades there has been an increase in dry season flows and a decrease in wet season flows in the Mekong mainstream. More significant changes are evident at upstream gauges with the effect attenuating downstream. This change has been attributed to development activities, particularly dams and reservoirs in the Upper Mekong Basin, rather than climate change, and to-date no statistically significant change in hydrology has been demonstrated to be caused by climate change.

A wide range of potential future impacts on water resources from climate change are plausible. River flows and water levels in the wet and dry seasons may increase or decrease dramatically, depending on the future scenario. Changes in river flow, water level, wet season duration and peaks, and dry season minimums may have profound impacts on water-dependent biodiversity and livelihoods. Upper Mekong Basin snowmelt is projected to dramatically decrease across all scenarios, particularly in the wet season. Dry season salinity intrusion is also projected to increase under all scenarios and models with more significant impacts in the drier overall scenario with upstream development generally only slightly offsetting these impacts.

3.1.1 Past and current conditions

The natural hydrological regime of the Mekong Basin is characterised by two major influences: the southwest monsoon and individual storms. The southwest monsoon between May and November is the main driver of the annual flood pulse of the Mekong River with a distinct seasonality in the annually hydrological regime between a wet season and a dry season. In addition, individual storm events caused by tropical depressions or cyclones, and usually formed in the South China Sea, pour down intense rainfall over the Lower Mekong Basin and therefore generate distinct individual peaks to the wet season flows. These generally occur during July-October.

The average annual flow of the Mekong is approximately 475km^3. Although the headwaters are located in China, the contribution to flow from the Upper Mekong Basin is relatively small (16%) by the time the river discharges to the sea. The major source of the discharge (>40%) stems from the left bank tributaries between Vientiane and Nakhon Phanom and between Pakse and Stung Treng. Due to the impact of the southwest monsoon, the hydrological regime of the Mekong is divided into four distinct phases (dry season, wet season and two transition phases in between). During the peak of the flood season (September), the mean monthly discharge at the Kratie gauge exceeds 36,000m^3/s while the mean monthly discharge of the driest month (April) amounts to approximately 2,200m^3/s.

The annual hydrological regime of the mainstream is illustrated in Figure 3.1 at Chiang Saen to capture mainstream flows entering from the Upper Mekong Basin, at Vientiane to present flows generated by climate condition in the upper part of the Lower Mekong Basin, at Pakse to investigate flows influenced by inflows from Mekong tributaries, and at Kratie to capture overall flows of the Mekong Basin. Characteristics of the flows over recent years (i.e. 2010-2014) are compared to flow conditions of 1995-2009. Flows in the wet season at Chiang Saen and Vientiane tend to be lower than the long term mean of 1995-2009. However, these trends could not obviously be seen at Pakse where flows are generally influenced by inflows from tributaries in the mid-basin of the Lower Mekong, and at Kratie where the flow condition is dominated by hydraulic features of the lower floodplain as much as flow from upstream.

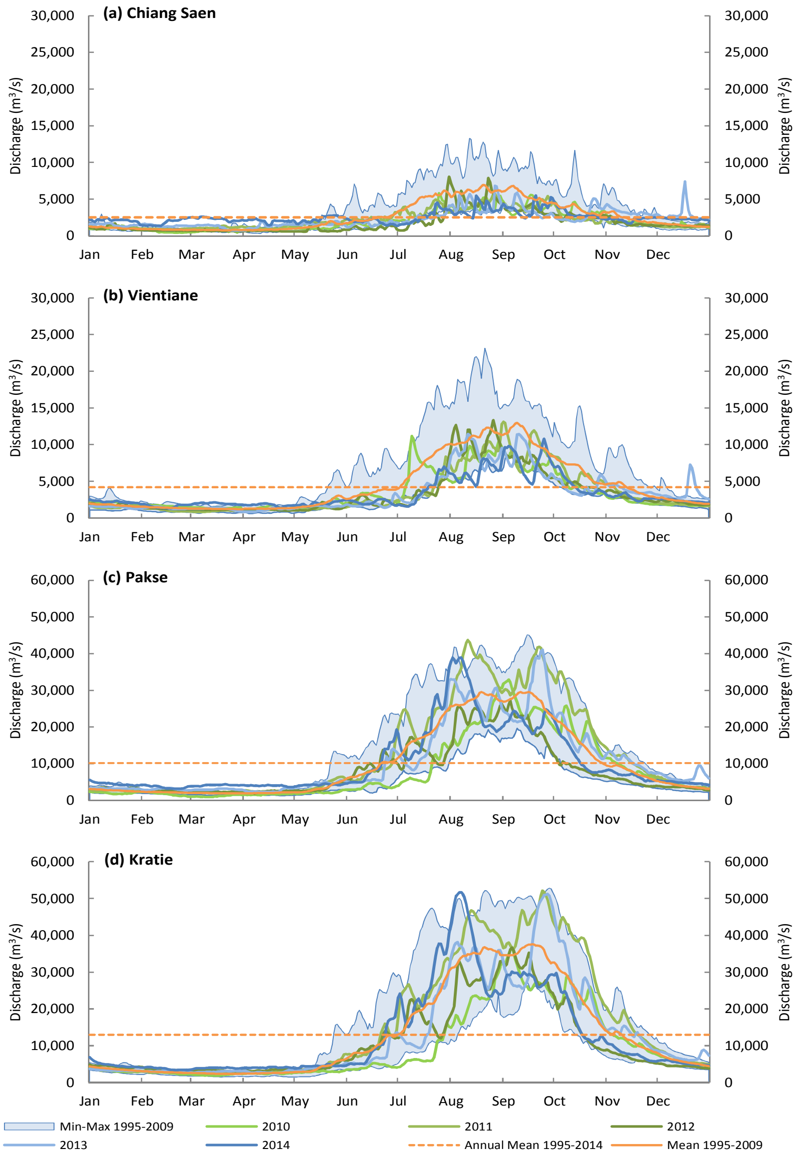


Figure 3.1: Flow characteristics from 2010 to 2014 relative to mean, maximum and minimum from 1995-2009 at (a) Chiang Saen; (b) Vientiane; (c) Pakse; and (d) Kratie (MRC, 2016a).

The preparatory State of the Basin Report (MRC, 2016a) identifies that dry season flows have increased over the recent past while wet season flows have decreased, at least at Chiang Saen. This is likely the result of the regulation of flow caused by dams in the upper Mekong (MRC, 2015c). These increases in flow in the dry season are in line with the flow changes predicted for the Definite Future Scenario in the Assessment of Basin-wide Development Scenarios[13] of the Basin Development

[13] Mekong River Commission (2011). Assessment of Basin-wide Development Scenarios, Cumulative impact assessment of the riparian countries' water resources development plans including mainstream dams and diversions, Main Report, Mekong River Commission Secretariat (MRCS), Vientiane.

Plan (BDP). There is no indication that these changes are a result of climate change. Change in seasonality of the flood season at Chiang Saen and Kratie stations could not be clearly observed for the period of 1995-2014 (MRC, 2016a).

Examining the annual discharge data from several gauges along the Mekong mainstream, Adamson (2006) found no trend since 1960 for the gauges at Vientiane and Chiang Saen. At stations further downstream the residual trend was a highly non-linear, quasi periodic structure probably related to long-term fluctuations in regional rainfall. Analysing the magnitude of annual, peak and low flows in several tributaries no systematic general trend was identified. However, Cochrane *et al.* (2014) examined pre and post 1991 historical water levels from six mainstream stations and one station at the Tonle Sap River and observed that the main cause of changes in key hydrological indicators that are related to ecosystem productivity (i.e. 7-day minimum water level, fall rates, number of water level fluctuations) were directly attributable to water infrastructure development rather than climate change. They illustrate that consistent with the modelling, there has been a modest observable increase in low season flows at Chiang Saen but that the effect diminishes downstream until it is negligible at Mukhadan in north-east Thailand. These results are consistent with MRC (2015c), which found an increase in dry season flows and a decrease in wet season flows as a result of re-regulation by the Lancang Hydropower Cascade.

Previous studies have failed to identify a statistically significant trend in discharge (Hapuarachchi *et al.* 2008; Hanh *et al.,* 2010; Xue *et al.,* 2011). MRC (2010a) examined the temporal distribution of seasonal flows over the last 80 to 90 years at the gauges of Vientiane and Kratie and identified no evidence at that time of significant impacts from human induced land use changes or from climate change that can be detected against the natural background variability, both long and short-term. However, in addition to an increase in dry season flows, Cochrane *et al.* (2014) show that there has been a statistically significant reduction of 23% and 11% in the water rising and falling rates respectively at Prek Kdam, providing evidence of a diminished Tonle Sap flood pulse in the post-1991 period. At Stung Treng and Prek Kdam, increases in 30-day minimum flows are strongly significant with a mean increase of 13% and 17% respectively. At Pakse, alterations to the number of fluctuations and rise rate became strongly significant after 1991. 30 of 39 Mekong Basin dams on the mainstream and tributaries were constructed after 1991 (MRC dams database, 2010).

Inomata and Fukami (2008) reconstructed historical hydrological data on the Tonle Sap system for the period 1982 to 2004 by multiple regression analysis. Results suggest that neither the volume of the Tonle Sap Lake nor the ratio between annual maximum storage and discharge and total discharge at the gauge of Kompong Cham changed significantly during the examined period. There was also no tendency found for more frequent flood and drought years. The estimated data for annual maximum discharge and the annual total of normal and reverse flow did not display any trend. In contrast, inflow from the floodplains into Tonle Sap has increased in recent years. According to the authors, this is in accordance with the water levels observed in the Mekong River. Arias *et al.* (2012) also found no significant changes in flood levels and flood extent of Tonle Sap Lake when analysing levels from 1986 to 2010.

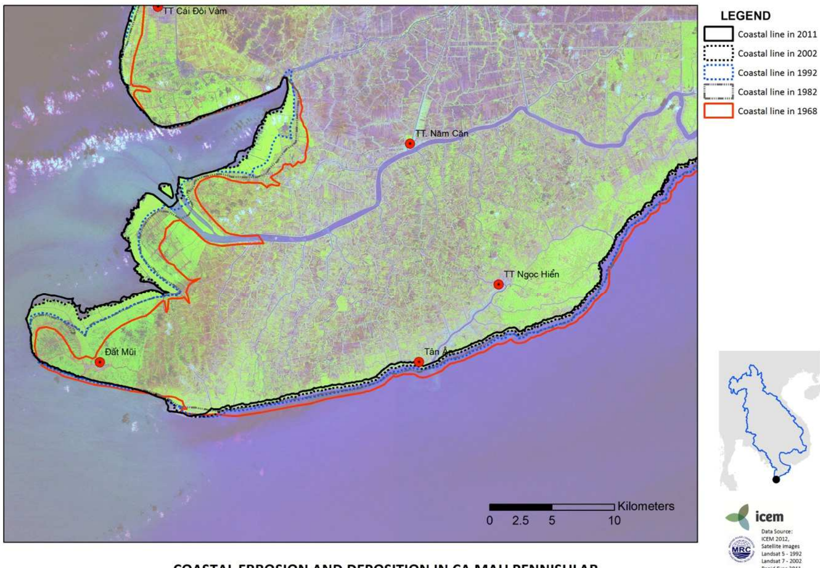
As identified earlier in this report, sea levels are rising around the world and the rate of rise is increasing. The average global rate was +1.7 mm/yr during the 20^{th} century, 1.8 mm/yr from 1961 to 2003, +3.1 mm/yr from 1993 to 2003 and +3.2 mm/yr from 1993 to 2012 (IPCC, 2013). According to

IPCC (2007b) sea-level rise along Asian coastlines is between +1.0 mm/yr and +3.0 mm/yr. MONRE Viet Nam (2009) report that sea level at Hon Dau rose at an average annual rate of about +3.0 mm/yr from 1993 to 2008, while Thuc (2012) reports an average rise of +2.8 mm/yr from several stations along the Vietnamese coast. Thang *et al.* (2010) reports a rise of +3.38 mm/yr at Vung Tau station in Southern Viet Nam between 1960 and 2008. Analysis of the Vung Tau gauging station by others indicates that sea levels have risen on average 4.2mm/yr between 1979 and 2006, compared to an average annual SLR of 1.8 and 2.0mm/yr in Shanghai and Hong Kong, respectively (Yu *et.al.,* 2002; Ding *et.al.,* 2001).[14]

Increasing sea levels are likely to lead to increased coastal erosion and salinity intrusion which extends further inland. Currently, 1.7 million hectares of the Vietnamese Mekong Delta (42%) is affected by salinity intrusion (ADPC, 2003). That study also found that salinity intrusion is the principal limiting factor in agricultural production (particularly for mono-crop rice cultivation) where most of the provinces with a high ratio of poor farmers are located.

Coastal erosion has also been reported, such as in the Ca Mau area where more than 600 hectares of land have been eroded, with 200 m wide strips of land lost in some locations (Chaudhry and Ruysschaert, 2007). Anthony *et al.* (2013) examined coastline dynamics, with results that point towards coastal retreat in the Mekong Delta from 2003 and 2011. Based on satellite data, an average of 4.4 m/yr of coastline retreat across the entire South sea shoreline, with higher rates of 12 m/yr on the Ca Mau peninsula was found.

The south coast of the Ca Mau peninsular which faces the East Sea is subject to significant coastal erosion, which can amount to 30 – 50 m annually (MRC, 2015d). However, the coast facing the West Sea is accreting, with mudflats tending to grow as the sediment is swept by currents around the peninsular (Figure 3.2).



COASTAL ERROSION AND DEPOSITION IN CA MAU PENNISULAR

Figure 3.2: Changes in the Ca Mau peninsula coastline 1968-2011 (MRC, 2016d).

[14] Analysis of SLR at Shanghai and Hong Kong used tidal data for the period: 1945 – 2001. The longer time period compared to the Vung Tau measurements will have an impact on the calculated annual SLR increment because sea level rise is a non-linear phenomena which has been accelerating in recent decades (c.f. Rahmstorf, 2007).

Evaluating the contribution of climate change to changes in water resources is difficult due to the confounding impacts from a range of other modifications, for example land use changes and water impoundment and abstraction. The often limited period of data availability also inhibits an analysis of long-term trends. Nevertheless, MRC (2010b) examined the historical record to determine whether or not there had been changes in mean annual flood in terms of its peak and volume and in the inter-annual variance in flood duration. It found no statistically significant impact of climate change on basin-scale hydrology.

While coastal erosion and salinity intrusion are real phenomena along the coast of the Delta region, how much of this is due to climate change and how much due to other factors such as changes in sediment discharge from the Mekong River and the removal of mangroves and other shoreline vegetation is not yet clear.

3.1.2 Projected climate change impacts

Mainstream hydrology and groundwater recharge

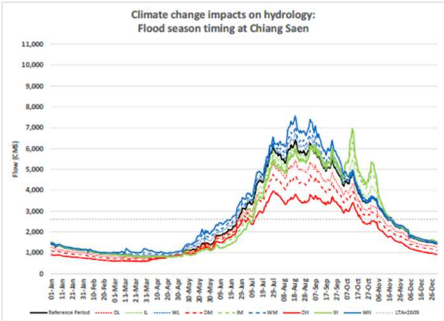
An analysis of projected hydrological impacts (MRC, 2016c) demonstrates that there is a wide range of potential impacts dependent on the model and resource concentration pathway scenario applied. It also considers that basin development is an important factor in determining the magnitude of projected impacts.

At the basin-wide scale, the range of annual water yield change as a result of climate change is projected to be from -31% to +20% by 2060 (given a baseline annual average total of 689 mm). As with projected rainfall changes, whilst the overall magnitude of change is influenced by the emissions scenario the direction of change is determined by the choice of climate model. The drier overall scenario projects large reductions in water yield while both the wetter overall and the increased seasonal variability scenarios project large increases in water yield.

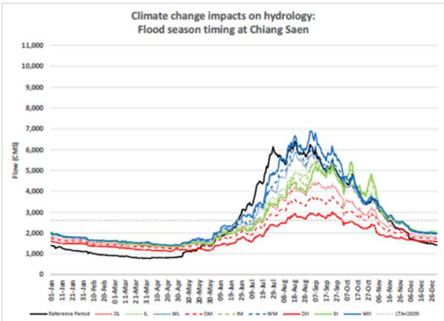
The pattern of projected change in water yield is more complex at the seasonal and monthly scales with large increases in water yield estimated for the late wet season and the dry season by the 'increased variability' scenario, whereas more consistent reductions in water yield are estimated for the 'drier overall' scenario and more consistent increases in water yield are estimated for the 'wetter overall' scenario.

The pattern of annual, seasonal and monthly projected change in groundwater recharge is similar to the pattern for water yield: the range of annual groundwater recharge change is estimated as -33% to +12% by 2060 (given a baseline annual average total of 365 mm). Within the broader picture of basin-wide impacts of climate change, there exists a more detailed picture of how impacts are predicted to vary throughout the basin. This spatial variation of impacts has been considered for an 'upper reach' of the LMB (between Chiang Saen and Kratie), a 'lower reach' of the LMB (downstream of Kratie and the Mekong Delta), and at individual key monitoring stations in the LMB.

Impact summaries at selected key monitoring stations are presented in MRC (2016c) and reproduced here for Chiang Saen (Figure 3.3) and Kratie (Figure 3.4). Daily average hydrographs showing the reference period and climate change scenarios are shown for: 2030, climate change scenarios; 2030, climate change and development scenarios; 2060, climate change scenarios; and 2060, climate change and development scenarios. A tabular summary for all key monitoring station impacts is also shown – the minimum, median and maximum predicted change impacts illustrate the range of predicted change impacts.

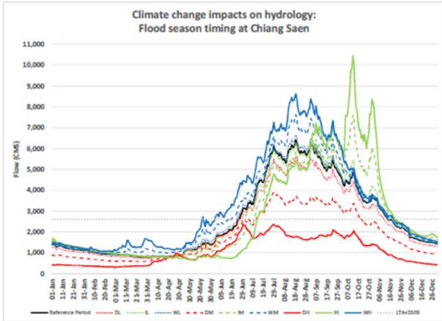


2030, climate change scenarios

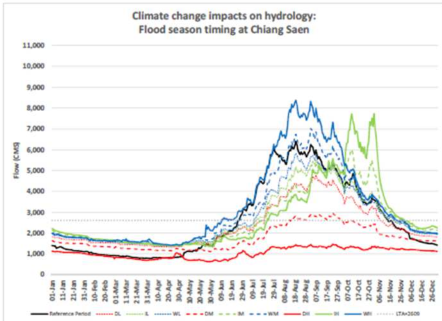


2030, climate change and development scenarios

		2030 CS	2030 CS + DS	2060 CS	2060 CS + DS
River flow	Annual	-31%	-31%	-59%	-59%
		-1%	-1%	2%	2%
		13%	13%	27%	27%
	Dry season	-30%	7%	-61%	-27%
		2%	36%	4%	38%
		8%	41%	18%	56%
	Wet season	-32%	-45%	-58%	-71%
		-2%	-14%	-1%	-13%
		15%	3%	30%	22%
River level	Annual	-0.79	-0.74	-1.59	-1.58
		-0.02	0.06	0.01	0.12
		0.32	0.38	0.63	0.67
	Dry season	-0.47	0.14	-0.98	-0.41
		0.03	0.58	0.06	0.60
		0.14	0.65	0.29	0.84
	Wet season	-1.11	-1.63	-2.20	-2.76
		-0.10	-0.46	-0.14	-0.48
		0.49	0.12	0.97	0.67
Flood timing	Onset	-8	0	#N/A	#N/A
		4	20	3	18
		16	47	19	48
	Offset	-21	0	-50	0
		0	19	0	19
		54	53	54	74
	Duration	-35	-90	#N/A	#N/A
		-6	-13	-7	-12
		12	7	38	28
Flood volume	Peak flow	-38%	-53%	-63%	-77%
		-2%	-15%	4%	-9%
		18%	8%	64%	31%
	Peak level	-2.07	-2.96	-3.65	-4.62
		-0.14	-0.81	0.19	-0.52
		0.82	0.30	2.80	1.31
	Volume	-46%	-78%	-100%	-100%
		-1%	-21%	1%	-17%
		17%	4%	41%	30%
	Shape	-60%	-36%	#DIV/0!	#DIV/0!
		0%	30%	#DIV/0!	#DIV/0!
		412%	649%	#DIV/0!	#DIV/0!
Drought	1-day flow	-26%	43%	-65%	-21%
		0%	72%	2%	73%
		23%	78%	35%	79%
	7-day flow	-26%	43%	-60%	-20%
		0%	72%	2%	73%
		24%	78%	35%	79%
	30-day flow	-26%	44%	-59%	-16%
		0%	71%	2%	72%
		26%	78%	38%	80%
	1-day level	-0.25	0.40	-0.64	-0.21
		0.00	0.68	0.02	0.69
		0.22	0.74	0.34	0.75
	7-day level	-0.25	0.41	-0.60	-0.19
		0.00	0.68	0.02	0.70
		0.23	0.74	0.34	0.75
	30-day level	-0.26	0.43	-0.60	-0.16
		0.00	0.68	0.02	0.70
		0.25	0.76	0.37	0.78

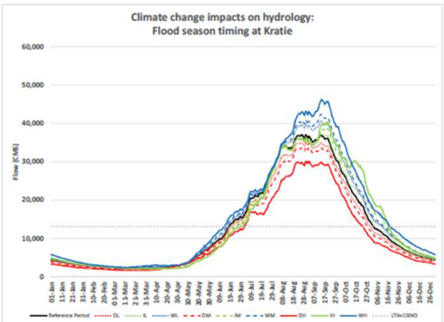


2060, climate change scenarios

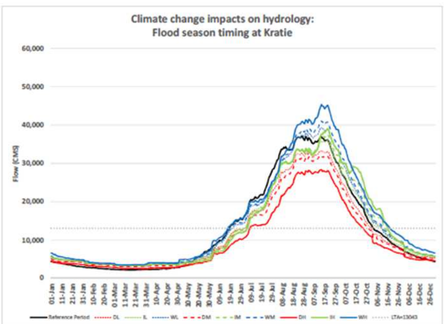


2060, climate change and development scenarios

Figure 3.3: Summary of projected hydrological impacts at Chiang Saen monitoring station under three model scenarios (wetter, drier, increased seasonality) and three emissions scenarios (RCP2.6, RCP4.5, RCP8.5) with and without development impacts to 2030 and 2060 (MRC, 2016c).

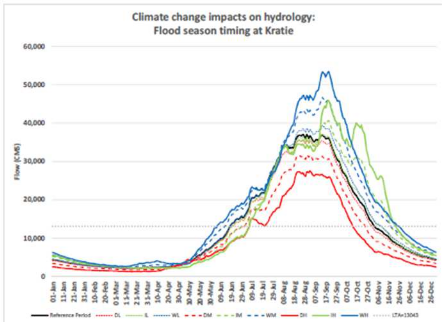


2030, climate change scenarios

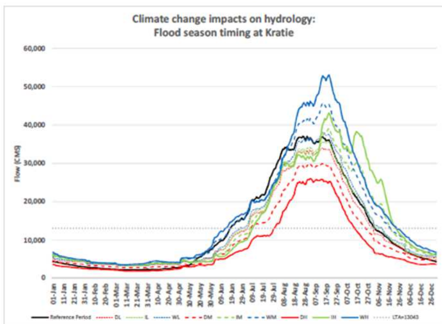


2030, climate change and development scenarios

		2030 CS	2030 CS + DS	2060 CS	2060 CS + DS
River flow	Annual	-22%	-25%	-34%	-38%
		3%	1%	4%	1%
		19%	17%	31%	28%
	Dry season	-25%	-6%	-43%	-29%
		8%	27%	5%	24%
		30%	46%	45%	60%
	Wet season	-21%	-29%	-32%	-40%
		1%	-5%	2%	-5%
		17%	11%	28%	22%
River level	Annual	-1.08	-1.13	-1.77	-1.95
		0.12	0.20	0.16	0.15
		0.87	0.91	1.35	1.29
	Dry season	-0.66	-0.12	-1.15	-0.74
		0.17	0.73	0.11	0.66
		0.71	1.18	1.08	1.39
	Wet season	-1.51	-2.14	-2.38	-3.17
		-0.03	-0.42	-0.04	-0.51
		1.03	0.63	1.62	1.19
Flood timing	Onset	-4	-1	-12	-4
		4	16	2	17
		15	20	19	42
	Offset	0	14	0	3
		15	15	15	15
		21	21	21	21
	Duration	-25	-30	-40	-61
		4	-6	2	-4
		20	17	35	25
Flood volume	Peak flow	-19%	-23%	-26%	-30%
		4%	1%	6%	3%
		25%	22%	44%	43%
	Peak level	-1.65	-2.16	-2.37	-2.83
		0.29	0.03	0.46	0.17
		1.72	1.55	3.03	2.96
	Volume	-30%	-37%	-44%	-55%
		6%	-5%	7%	-4%
		26%	18%	43%	33%
	Shape	-5%	30%	-2%	-26%
		50%	55%	39%	41%
		72%	72%	65%	67%
Drought	1-day flow	-26%	17%	-43%	-13%
		-3%	53%	-4%	56%
		11%	62%	20%	65%
	7-day flow	-25%	18%	-43%	-12%
		-3%	53%	-4%	56%
		11%	62%	21%	65%
	30-day flow	-25%	16%	-43%	-13%
		-2%	51%	-3%	54%
		13%	60%	24%	67%
	1-day level	-0.37	0.24	-0.62	-0.18
		-0.04	0.73	-0.05	0.77
		0.15	0.86	0.28	0.90
	7-day level	-0.36	0.25	-0.62	-0.18
		-0.04	0.74	-0.05	0.77
		0.16	0.86	0.29	0.91
	30-day level	-0.37	0.23	-0.63	-0.19
		-0.03	0.72	-0.05	0.75
		0.19	0.86	0.34	0.94



2060, climate change scenarios



2060, climate change and development scenarios

Figure 3.4: Summary of projected hydrological impacts at Kratie monitoring station under three model scenarios (wetter, drier, increased seasonality) and three emissions scenarios (RCP2.6, RCP4.5, RCP8.5) with and without development impacts to 2030 and 2060 (MRC, 2016c).

Selected impacts at Chiang Saen (in the upper LMB) and Kratie (in the lower LMB) are further summarized in Table 3.1 and highlighted as follows:

- The range of annual river flow change, for the 2060 climate change scenarios, is estimated as -59% to +27% at Chiang Saen and -34% to +31% at Kratie; for the climate change and development scenarios this range becomes -31% to +13% at Chiang Saen and -25% to +17% at Kratie. A median estimate of annual river flow change predicts, for 2060, only a small change of -1% to +1% at both locations;
- The corresponding range of annual river level change, for the 2060 climate change scenarios, is estimated as -1.59m to +0.63m at Chiang Saen and -1.77m to +1.35m at Kratie; and for the climate change and development scenarios -0.74m to +0.38m at Chiang Saen and -1.13m to +0.91m at Kratie. A median estimate of annual river level change predicts an increase in levels of +0.06m and +0.20m for the 2060 climate change and development scenarios, at Chiang Saen and Kratie respectively;
- For the 2060 climate change scenarios, wet season duration is predicted to vary within a range of no wet season to +38 days (longer) at Chiang Saen and -40 days (shorter) to +35 days (longer) at Kratie; for the climate change and development scenarios this range becomes -90 days to +7 days at Chiang Saen and -30 days to +17 days at Kratie. A median estimate of wet season duration change tends to predict a shorter wet season: -7 days and -13 days at Chiang Saen and +2 days and -6 days at Kratie, for the climate change scenarios and climate change and development scenarios respectively. A further feature of the wet season is a general tendency for it to be delayed, with both onset date and offset date typically occurring later in the year;
- The range of wet season peak flow change, for the 2060 climate change scenarios, is estimated as -63% to +64% at Chiang Saen and -26% to +44% at Kratie; for the climate change and development scenarios this range becomes -53% to +8% at Chiang Saen and -23% to +22% at Kratie. A median estimate of wet season peak flow change predicts, for 2060, only a small change of +4% and +6% for the climate change scenarios, and -15% and +1% for the climate change and development scenarios, at Chiang Saen and Kratie respectively;
- The corresponding range of wet season peak level change, for the 2060 climate change scenarios, is estimated as -3.65m to +2.80m at Chiang Saen and -2.37m to +3.03m at Kratie; and, for the climate change and development scenarios, -2.96m to +0.30m at Chiang Saen and -2.16m to +1.55m at Kratie. A median estimate of wet season peak level change predicts, for 2060, a change of +0.19m and -0.81m for the climate change scenarios, and +0.46m and +0.03m for the climate change and development scenarios, at Chiang Saen and Kratie respectively;
- The range of dry season minimum 1-day flow change, for the 2060 climate change scenarios, is estimated as -65% to +35% at Chiang Saen and -43% to +20% at Kratie; for the climate change and development scenarios this range becomes +43% to +78% at Chiang Saen and +17% to +62% at Kratie. A median estimate of dry season minimum 1-day flow change predicts, for 2060, a change of +2% and +72% for the climate change scenarios, and -4% and +53% for the climate change and development scenarios, at Chiang Saen and Kratie respectively; and

- The corresponding range of dry season minimum 1-day water level change, for the 2060 climate change scenarios, is estimated as -0.64m to +0.34m at Chiang Saen and -0.62m to +0.28m at Kratie; and, for the climate change and development scenarios, +0.40m to +0.74m at Chiang Saen and +0.24m to +0.86m at Kratie. A median estimate of dry season minimum 1-day level change predicts, for 2060, a change of +0.02m and +0.68m for the climate change scenarios, and -0.05m and +0.73m for the climate change and development scenarios, at Chiang Saen and Kratie respectively.

Table 3.1: The range in selected hydrological impacts due to (a) climate change and (b) climate change and development scenarios projected to 2060 at Chiang Saen and Kratie monitoring stations (MRC, 2016c).

(a)

	Climate change scenarios			
	Min.		Max.	
	Chiang Saen	Kratie	Chiang Saen	Kratie
Annual river flow	-59%	-34%	27%	31%
Annual river level	-1.59	-1.77	0.63	1.35
Flood season duration	#N/A	-40	38	35
Flood season peak flow	-63%	-26%	64%	44%
Flood season peak level	-3.65	-2.37	2.80	3.03
Drought season minimum 1-day flow	-65%	-43%	35%	20%
Drought season minimum 1-day level	-0.64	-0.62	0.34	0.28

(b)

	Climate change and development scenarios			
	Min.		Max.	
	Chiang Saen	Kratie	Chiang Saen	Kratie
Annual river flow	-31%	-25%	13%	17%
Annual river level	-0.74	-1.13	0.38	0.91
Flood season duration	-90	-30	7	17
Flood season peak flow	-53%	-23%	8%	22%
Flood season peak level	-2.96	-2.16	0.30	1.55
Drought season minimum 1-day flow	43%	17%	78%	62%
Drought season minimum 1-day level	0.40	0.24	0.74	0.86

USAID (2013) examined a single model and emissions scenario and also identify potentially significant changes in the onset and the duration of the hydro-biological seasons defined by MRC (2009), with the wet season and first transition season starting earlier and the dry season and the second transition season delayed. The delay in the dry season was projected to be strongest in the upper reaches and less pronounced in the lower reaches of the Mekong. Flow volume was projected to increase between Chiang Saen and Kratie with this mostly occurring in the wet season. The height of the flood peak and the variability of flows were also projected to increase.

Snowmelt

The change in average annual, dry season and wet season Upper Mekong Basin snowmelt for the selected climatic scenarios is summarized in Table 3.2 (MRC, 2016c). These results indicate that:

- The change in annual snowmelt is projected to vary within a range of -57.5 mm to -5.7 mm by 2060 (-34.1 mm to -7.4 mm by 2030);
- The change in dry season snowmelt is projected to vary within a range of -2.8 mm to +11.8 mm by 2060 (+1.5 mm to +6.1 mm by 2030); and
- The change in wet season snowmelt is projected to vary within a range of -54.7 mm to -7.2 mm by 2060 (-37.2 mm to -9.3 mm by 2030).

In all cases the variation in projected snowmelt is primarily associated with the choice of both GCM scenario and emissions scenario (the increased seasonal variability GCM, high emission (RCP8.5) scenario or the wetter overall GCM, low emission (RCP2.6) scenario)

According to MRC (2016c), across the range of climate scenarios there is a range of projected change in monthly snowmelt of -21.0 mm to +4.7 mm (by 2060). The variations in projected snowmelt change tend to be greatest during the early wet season (May: -21.0 mm to +0.4 mm by 2060). The greatest reductions in projected snowmelt tend to occur during the early wet season, associated with the high emissions (RCP8.5) scenarios; and the greatest increases tend to occur in the late dry season, associated with the wetter overall and high and medium emissions scenarios.

Table 3.2: Summary of projected changes in annual, dry season and wet season Upper Mekong Basin snowmelt to 2030 and 2060 under three RCPs (2.6; 4.5; 8.5) and three model scenarios (drier overall, wetter overall, increased seasonality) (MRC, 2016c).

Annual	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	-12.8	-9.9	-21.4	-34.3	-33.3	-54.7
Increased seasonal variability	-12.5	-9.7	-21.4	-35.1	-34.1	-57.5
Wetter overall	-7.4	-5.7	-12.4	-20.3	-19.7	-34.3

Dry season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	1.9	1.4	2.9	3.8	3.8	-0.5
Increased seasonal variability	1.5	1.2	2.2	2.3	2.3	-2.8
Wetter overall	2.0	1.5	3.5	6.3	6.1	11.8

Wet season	Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
	2030	2060	2030	2060	2030	2060
Drier overall	-14.7	-11.4	-24.3	-38.1	-37.2	-54.2
Increased seasonal variability	-14.0	-10.9	-23.6	-37.3	-36.4	-54.7
Wetter overall	-9.3	-7.2	-16.0	-26.6	-25.8	-46.1

Salinity intrusion

The MRC (2016c) basin-wide assessment of climate change impacts on the hydrology of the Lower Mekong Basin assessed the projected dry season salinity changes in the Mekong Delta due to climate change. Baseline years of 1998 and 2004 were chosen as 'representative dry years' from which to assess projected changes, with salinity impacts determined as the percentage change in area for the Mekong Delta for which the salinity concentrations:

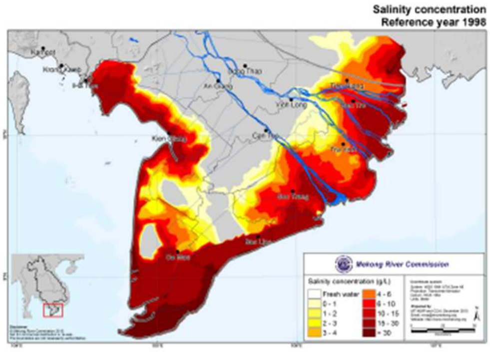
- Exceed 4g/l;
- Exceed 4g/l for a range of duration thresholds; and
- Exceed 1g/l for a range of duration thresholds.

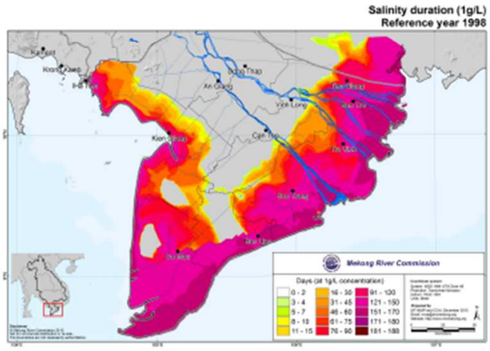
The results demonstrate (Figures 3.5 and 3.6) that for both 2030 and 2060 no consistent patterns relating the predicted change in salinity to GCM or emission scenario can be identified, although it is notable that the wetter overall GCM high emission (RCP8.5) scenario is associated with the lowest increases / greatest reductions in predicted salinity impacts. The greatest increases in projected salinity impacts to 2030 tend to be for the increased seasonal variability model to 2030 and the drier overall model to 2060. In summary:

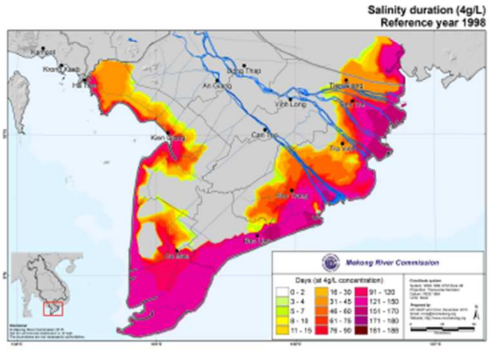
- The change in net salinity concentration for the representative year 1998 is predicted to vary within a range of -13 % to +8 % by 2030 and -18 % to +12 % by 2060;
- For salinity concentrations exceeding 1g/l, the change in net salinity duration for the representative year 1998 is predicted to vary within a range of -13 % to +8 % by 2030 and 18 % to +12 % by 2060;
- For salinity concentrations exceeding 4g/l, the change in net salinity duration for the representative year 1998 is predicted to vary within a range of -14 % to +16 % by 2030 and -20 % to +17 % by 2060;
- The change in net salinity concentration for the representative year 2004 is predicted to vary within a range of no change to +22 % by 2030 and -8 % to +28 % by 2060;
- For salinity concentrations exceeding 1g/l, the change in net salinity duration for the representative year 2004 is predicted to vary within a range of no change to +22 % by 2030 and -8 % to +28 % by 2060;
- For salinity concentrations exceeding 4g/l, the change in net salinity duration for the representative year 2004 is predicted to vary within a range of -1 % to +30 % by 2030 and -4 % to +34 % by 2060.

From both 1998 and 2004 baseline years there is no uniform impact on the projected change in salinity as a result of basin development. The range of projected change in Mekong Delta salinity concentration due to both climate change and development scenarios to 2030 is estimated as -11% to +12% for 1998 and -9% to +6% for 2004; the median estimates of change are no change for 1998 and -2% for 2004. The range of projected change in Mekong Delta salinity duration is estimated as -11% to +18% and -4% to +18% for a 1g/l concentration threshold and 4g/l concentration threshold respectively for 1998, and - 9% to +6% and +5% to +14% for a 1g/l concentration threshold and 4g/l concentration threshold respectively for 2004. Corresponding median estimates of change are no change and +8% for 1998 and -2% and +9% for 2004.

The range of projected change in Mekong Delta salinity concentration due to both climate change and development scenarios to 2060 is estimated as -21% to +32% for 1998 and -22% to +49% for 2004; the median estimates of change are -1% for 1998 and +6% for 2004. The range of projected change in Mekong Delta salinity duration is estimated as -21% to +19% and -16% to +16% for a 1g/l concentration threshold and 4g/l concentration threshold respectively for 1998, and - 22% to +49% and -6% to +56% for a 1g/l concentration threshold and 4g/l concentration threshold respectively for 2004. Corresponding median estimates of change are -2% and +3% for 1998 and +6% and +14% for 2004.







1998		Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
		2030	2060	2030	2060	2030	2060
Drier overall	CS	-5%	-8%	8%	12%	-3%	6%
	CS + DS	3%	8%	5%	12%	12%	32%
Increased seasonal variability	CS	3%	4%	1%	5%	3%	-7%
	CS + DS	0%	5%	-1%	-2%	0%	-4%
Wetter overall	CS	-9%	-9%	1%	-2%	-13%	-18%
	CS + DS	-5%	-2%	-8%	-21%	-11%	-10%

(a) Change in area (concentration thresholds)

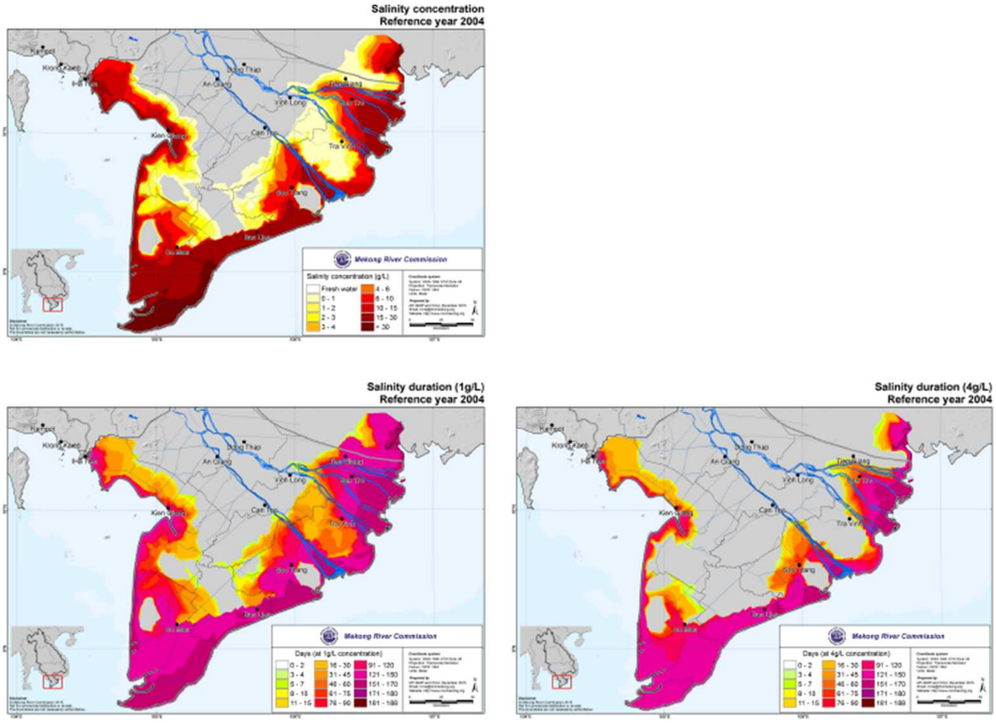
1998		Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
		2030	2060	2030	2060	2030	2060
Drier overall	CS	-5%	-8%	8%	12%	-3%	6%
	CS + DS	3%	8%	5%	12%	12%	19%
Increased seasonal variability	CS	3%	4%	1%	5%	3%	-7%
	CS + DS	0%	5%	-1%	-2%	18%	-4%
Wetter overall	CS	-9%	-9%	1%	-2%	-13%	-18%
	CS + DS	-5%	-2%	-8%	-21%	-11%	-10%

(b) Change in area (duration thresholds > 1g/l)

1998		Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
		2030	2060	2030	2060	2030	2060
Drier overall	CS	-13%	-9%	16%	17%	-2%	4%
	CS + DS	10%	11%	13%	16%	18%	0%
Increased seasonal variability	CS	12%	12%	9%	14%	12%	-8%
	CS + DS	8%	9%	6%	3%	12%	1%
Wetter overall	CS	-9%	-10%	9%	6%	-14%	-20%
	CS + DS	-2%	3%	-2%	-16%	-4%	-4%

(c) Change in area (duration thresholds > 4g/l)

Figure 3.5: Salinity concentration and duration above 1g/l and 4g/l in the reference year 1998 and changes in area under both climate change (CS) and climate change and development (CS + DS) scenarios for drier overall, increased seasonal variability and wetter overall models to 2030 and 2060 (MRC, 2016c).



2004		Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
		2030	2060	2030	2060	2030	2060
Drier overall	CS	4%	2%	22%	28%	9%	20%
	CS + DS	-7%	1%	1%	30%	6%	49%
Increased seasonal variability	CS	16%	16%	15%	23%	20%	7%
	CS + DS	-9%	-3%	-8%	11%	-8%	6%
Wetter overall	CS	2%	2%	14%	12%	0%	-8%
	CS + DS	5%	12%	2%	-22%	-2%	-4%

(a) Change in area (concentration thresholds)

2004		Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
		2030	2060	2030	2060	2030	2060
Drier overall	CS	4%	2%	22%	28%	9%	20%
	CS + DS	-7%	1%	1%	30%	6%	49%
Increased seasonal variability	CS	16%	16%	15%	23%	20%	7%
	CS + DS	-9%	-3%	-8%	11%	-8%	6%
Wetter overall	CS	2%	2%	14%	12%	0%	-8%
	CS + DS	5%	12%	2%	-22%	-2%	-4%

(b) Change in area (duration thresholds > 1g/l)

2004		Low emission (RCP2.6)		Medium emission (RCP4.5)		High emission (RCP8.5)	
		2030	2060	2030	2060	2030	2060
Drier overall	CS	3%	2%	30%	34%	7%	12%
	CS + DS	6%	13%	9%	44%	11%	56%
Increased seasonal variability	CS	27%	26%	25%	31%	30%	4%
	CS + DS	5%	9%	6%	17%	5%	14%
Wetter overall	CS	1%	1%	20%	18%	-1%	-4%
	CS + DS	14%	17%	12%	-6%	10%	9%

(c) Change in area (duration thresholds > 4g/l)

Figure 3.6: Salinity concentration and duration above 1g/l and 4g/l in the reference year 2004 and changes in area under both climate change (CS) and climate change and development (CS + DS) scenarios for drier overall, increased seasonal variability and wetter overall models to 2030 and 2060 (MRC, 2016c).

Based on their analysis of a single scenario and model USAID (2013) found that changes in salinity intrusion under a 30cm sea level rise during 2045-2069 are expected to be moderate during the wet season but significantly more severe during the dry season. During the dry season, salinity (at 4g/l) is expected to increase over 133,000 ha of the Mekong Delta with maximum salinity concentration increasing by more than 50 per cent compared to the reference period. Under this scenario an area of 1.2 million ha is projected to experience changes in salinity between -5 and +5 per cent. An area of 2 million ha is projected to be subjected to a -2 to +2 per cent change in days per year with salinity reaching a concentration of 4 g/l or more. The 4g/l salinity concentration contour will slowly move inland. However, the impact is highly sensitive to the use of human built water control infrastructure, and increased dry season flows combined with high connectivity throughout the Delta. According to the World Bank (2010), the total area of the Vietnamese portion of the Delta affected by salinity intrusion with concentrations higher than 4 g/l may increase from 1,303,000 ha to 1,723,000 ha with a 30 cm sea level rise.

Despite many areas of the Delta being protected from salinity intrusion by infrastructure, the area is still vulnerable. USAID (2013) find that aquaculture farmers should be able to manage salinity levels quite well through choice of species – some being tolerant of a wide range of salinities. However, freshwater farms may need to move inland in some places, while new areas for brackish aquaculture are likely to emerge. Trieu and Phong (2015) found that area available for Pangasius farming could decline by up to 11% due to inward sift in salinity intrusion; a finding consistent with that of Nguyen *et al.* (2014).

There is likely to be a high vulnerability of rice-based systems to salinity intrusion although the main vulnerability of irrigated rice in Kien Giang was likely to be due to increased temperature (USAID, 2013). ICEM (2010) also find that agricultural productivity of the Delta could be decreased by increased salinity resulting from sea-level rise. Deb *et al.* (2015) modelled the impact of increased salinity on rice production in Ca Mau province of Viet Nam using the AquaCrop model and found that Summer-Autumn rice yields would be expected to decline. The decline was due to increased minimum temperatures and increased salinity. However, Autumn-Winter paddy rice yield increased – likely due to more water availability. As a result, a shift in transplanting dates could be beneficial – later for summer/autumn rice and earlier for autumn/winter rice.

MRC (2015d) find that the composition of aquatic invertebrates is likely to change as species that can tolerate the conditions increase relative to those that are not tolerant, and sea level rise in the Ca Mau peninsula will leave Mangroves highly vulnerable as both species diversity and coverage is affected. This was considered the most significant threat to mangroves and mudflat wetlands and a reduction in mangroves will further reduce storm protection potentially leading to increased coastal erosion.

3.2 Vegetation and forests

Key findings

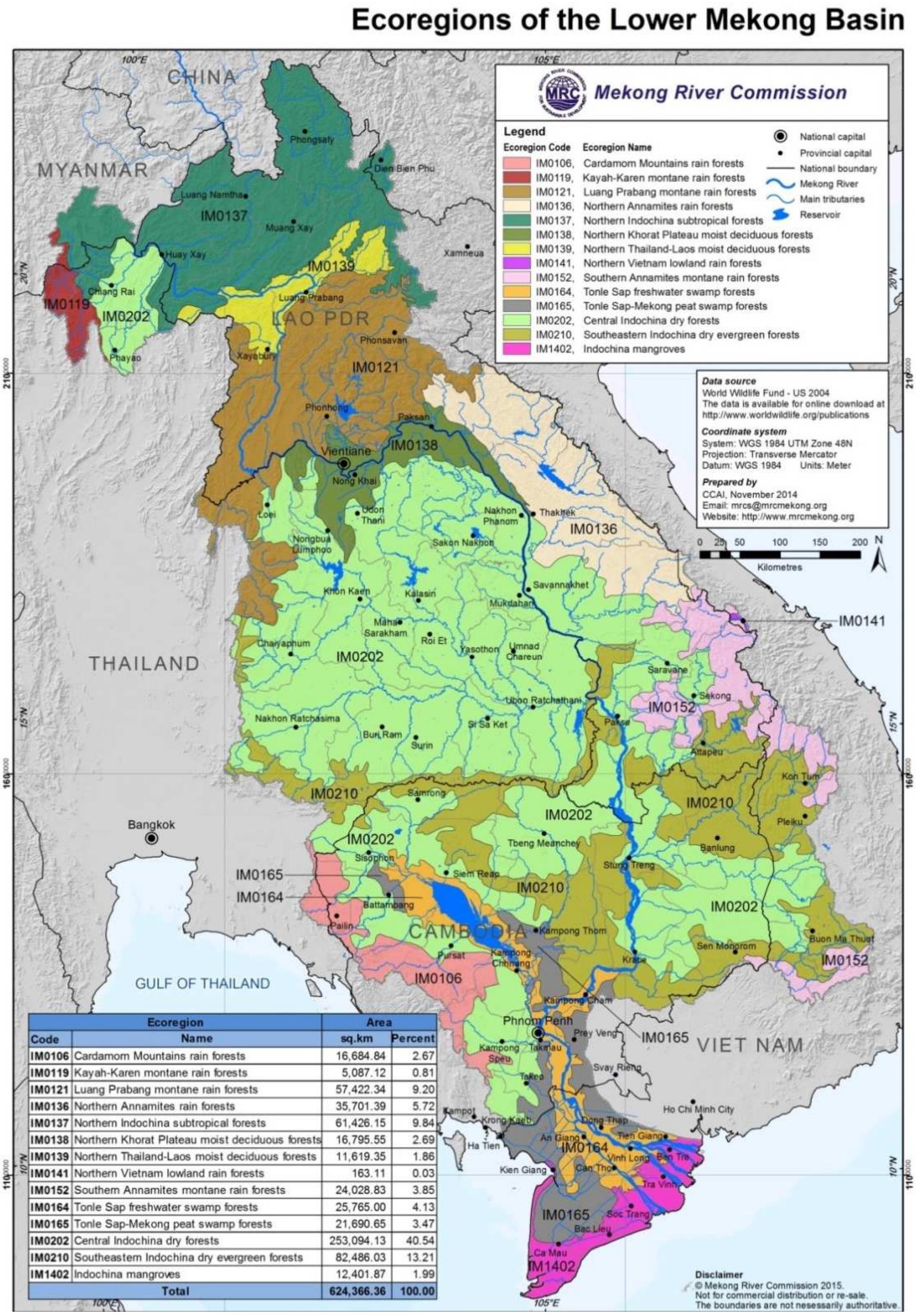
There have been very significant changes in vegetation and forests over recent decades. However, to-date none of this change has been directly attributed to climate change. Legal and illegal logging, clearing for agriculture and the growth of plantation forests and shrubland are more significant sources of change in vegetation and forest cover. Future impacts on vegetation and forests have not been assessed other than through changes to habitats, biodiversity and agriculture as reported in other sections of this report. The reduction in area of broadleaved evergreen forest and mangroves, while partly compensated for by an increase in broadleaved deciduous forests in some areas, is likely to reduce the adaptive capacity and buffering of climate change for populations dependent on forest resources.

3.2.1 Past and current conditions

Within the Lower Mekong Basin (LMB) there are three broad terrestrial habitat types: Tropical and Subtropical Dry Broadleaf Forests (which comprise 54% of the area of the LMB); Tropical and Subtropical Moist Broadleaf Forests (which comprise 44%); and Mangroves (which comprise 2As described in Olsen *et al.* (2001), the Dry Broadleaf Forests generally exhibit high annual rainfall but with extended dry seasons which can last several months. Seasonal drought is a major determinant of ecological process and biodiversity. They are less biologically diverse than rainforests yet harbour an abundance of large vertebrate fauna. The Wet Broadleaf Forests are characterised by low variability in annual temperature and high levels of rainfall. Forest composition is primarily semi-evergreen, evergreen and deciduous and contains some of the highest species diversity of any major terrestrial habitat type. Mangroves occur along the sheltered tropical and subtropical shoreline, subject to the ebb and flow of tides, fortnightly spring and neap tides, and seasonal weather fluctuations. They are comprised of around 60 species of salt-tolerant tree and are an important nursery habitat for many aquatic species.

Within the LMB the three major habitat types are comprised of 14 Ecoregions (Figure 3.7), which were identified based on the following parameters:

- Species richness
- Endemism
- Higher taxonomic uniqueness (e.g. unique genera or families, relict species or communities, primitive lineages)
- Extraordinary ecological or evolutionary phenomena (e.g. extraordinary adaptive radiations, intact large vertebrate assemblages, presence of migrations of large vertebrates)
- Global rarity of the major habitat type



Ecoregion		Area	
Code	Name	sq.km	Percent
IM0106	Cardamom Mountains rain forests	16,684.84	2.67
IM0119	Kayah-Karen montane rain forests	5,087.12	0.81
IM0121	Luang Prabang montane rain forests	57,422.34	9.20
IM0136	Northern Annamites rain forests	35,701.39	5.72
IM0137	Northern Indochina subtropical forests	61,426.15	9.84
IM0138	Northern Khorat Plateau moist deciduous forests	16,795.55	2.69
IM0139	Northern Thailand-Laos moist deciduous forests	11,619.35	1.86
IM0141	Northern Vietnam lowland rain forests	163.11	0.03
IM0152	Southern Annamites montane rain forests	24,028.83	3.85
IM0164	Tonle Sap freshwater swamp forests	25,765.00	4.13
IM0165	Tonle Sap-Mekong peat swamp forests	21,690.65	3.47
IM0202	Central Indochina dry forests	253,094.13	40.54
IM0210	Southeastern Indochina dry evergreen forests	82,486.03	13.21
IM1402	Indochina mangroves	12,401.87	1.99
Total		624,366.36	100.00

Figure 3.7: Ecoregions of the Lower Mekong Basin

The Ecoregions of the LMB are:

Tropical and Subtropical Moist Broadleaf Forests

1. Cardamom Mountains Rain Forests
2. Kayah-Karen Montane Rain Forests
3. Luang Prabang Montane Rain Forests
4. Northern Annamites Rain Forests
5. Northern Indochina Subtropical Forests
6. Northern Khorat Plateau Moist Deciduous Forests
7. Northern Thailand-Laos Moist Deciduous Forests

8. Northern Vietnam Lowland Rain Forests
9. Southern Annamites Montane Rain Forests
10. Tonle Sap Freshwater Swamp Forests
11. Tonle Sap-Mekong Peat Swamp Forests

Tropical and Subtropical Dry Broadleaf Forests

12. Central Indochina Dry Forests
13. South-eastern Indochina Dry Evergreen Forests

Mangroves

14. Indochina Mangroves

Vegetation and forest cover across the Lower Mekong Basin (LMB) is best ascertained by an assessment of landcover data which provides fine-grain detail of the surface cover that dominates each square kilometre of the LMB. There are four MRC landcover datasets available, for the years 1993, 1997, 2003 and 2010 (MRC, 2001; 2011b; Stibig, 1997). These data serve as a baseline and snapshots of ecosystem change between 1997 and 2010. In order to compare landcover data between years a consistent cover categorization is needed. Because of the differences between the years, also referred to as index periods, it was necessary to develop a process of merging the landcover data from the 1990s to 2010. The categories of shifting cultivation, paddy rice, aquaculture, industrial orchard and coniferous forest did not exist in the 1990s. Similarly, there were numerous sub categories of shrubland, forest and other covers that were not used in all datasets.

Using the most recent landcover layers for the LMB (2010), two landcover types comprise the majority (51%) of the total area (Table 3.3). These are broadleaved deciduous forest (28.85%) and paddy rice (22.47%). These types represent a combination of natural and human influenced covers. For the purpose of this report, natural covers are considered to be forest types (including bamboo, mangrove and flooded forest), shrubland and grassland, and natural water bodies. In 2003 the landcover type covering the largest area was broadleaved evergreen forest (29.91%).

Table 3.3: Relative frequency of landcover basin-wide in 2003 and 2010 (MRC, 2016e).

Land cover	2003		2010		Change
	Km^2	%	Km^2	%	%
Broadleaved Deciduous Forest	133,024	21.30	180,436	28.85	+7.56
Paddy Rice	154,995	24.81	140,540	22.47	-2.34
Shrubland	20,988	3.36	70,587	11.29	+7.93
Broadleaved Evergreen Forest	186,798	29.91	65,177	10.42	-19.48
Annual Crop	42,500	6.80	52,461	8.39	+1.58
Industrial plantation	4,760	0.76	25,343	4.05	+3.29
Urban Area	15,690	2.51	15,780	2.52	+0.01
Water Body	12,135	1.94	14,667	2.35	+0.40
Orchard	3,663	0.59	12,123	1.94	+1.35
Shifting Cultivation	14,242	2.28	9,724	1.56	-0.73
Grassland	13,880	2.22	8,637	1.38	-0.84
Aquaculture	2,101	0.34	6,886	1.10	+0.76
Bamboo Forest	9,167	1.47	5,700	0.91	-0.56
Flooded Forest	4,360	0.70	4,886	0.78	+0.08
Coniferous Forest	232	0.04	3,900	0.62	+0.59
Bare Soil	2,851	0.46	3,843	0.61	+0.16
Marsh/Swamp Area	913	0.15	1,866	0.30	+0.15
Forest Plantation	480	0.08	1,498	0.24	+0.16
Mangrove	1,839	0.29	1,303	0.21	-0.09

The landcover types that increased the most in area across the LMB between 2003 and 2010 (Figure 3.7) were shrubland (+7.93%), broadleaved deciduous forest (+7.56%), industrial plantation (+3.29%), annual crop (+1.58%) and orchard (+1.35%). Those that decreased the most in area between 2003 and 2010 were broadleaved evergreen forest (-19.48%), paddy rice (-2.34%), and grassland (+0.84%).

Different ecoregions are more or less dominated by natural and human land covers, with the higher elevation ecoregions generally exhibiting a greater dominance of natural land cover, particularly deciduous, evergreen and coniferous forest. These include the ecoregions of the Cardamom Mountains Rain Forests, the Kayah-Karen Montane Rain Forests and the Northern Khorat Plateau Moist Deciduous Forests amongst others. Lowland areas and those ecoregions with significant freshwater systems such as the Tonle Sap Freshwater Swamp Forests, the Central Indochina Dry Forests and the Indochina Mangroves ecoregions are dominated by annual crops and paddy rice.

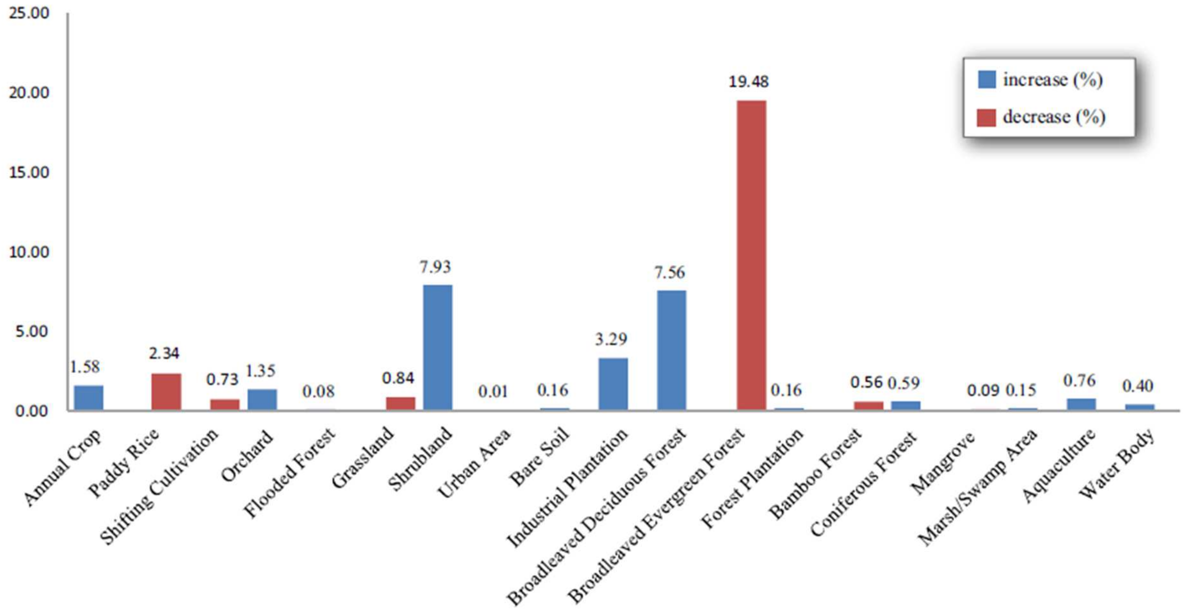


Figure 3.7: Land cover changes in the Lower Mekong Basin between 2003 and 2010 (MRC, 2016e).

Of the 14 ecoregions that occur within the LMB the largest by some distance is the Central Indochina Dry Forests ecoregion which occurs in all four Member Countries encompassing an area of 253,147 km^2 (Table 3.4). The only other ecoregion to occur in all four Member Countries is the South-eastern Indochina Dry Forests, which covers an area of 82,504 km^2. The smallest ecoregion is the Northern Vietnam Lowland Rain Forests, which only takes up 163 km^2 of the LMB within the central highlands of Viet Nam. Only four ecoregions occur only within the LMB area of one member country. These are the Kayah-Karen Montane Rainforests (Thailand), the Northern Annamites Rain Forests, the Northern Thailand-Laos Moist Deciduous Forests (both Lao PDR), and the Northern Vietnam Lowland Rain Forests (Viet Nam).

Table 3.4: Summary of the total area (km²) of ecoregions within the LMB of each member country.

Ecoregion	Cambodia	Lao PDR	Thailand	Viet Nam	Total
Cardamom mountains rainforest	15,162	-	1,526	-	**16,688**
Kayah-Karen montane rainforests	-	-	4,555	-	**4,555**
Luang Prabang montane rainforests	-	47,360	10,075	-	**57,435**
Northern annamites rain forest	-	35,073	-	636	**35,709**
Northern Indochina subtropical forests	-	51,195	3,538	1,398	**56,130**
Northern Khorat Plateau Moist Deciduous Forests	-	5,562	11,237	-	**16,799**
Northern Thailand-Laos Moist Deciduous Forests	-	11,608	14	-	**11,622**
Northern Vietnam Lowland Rain Forests	-	11	-	152	**163**
Southern Annamites Montane Rain Forests	300	14,782	-	8,952	**24,034**
Tonle Sap Freshwater Swamp Forests	15,796	-	-	9,972	**25,768**
Tonle Sap-Mekong Peat Swamp Forests	9,905	-	-	11,786	**21,691**
Central Indochina Dry Forests	69,933	30,404	146,136	6,674	**253,147**
South-eastern Indochina Dry Evergreen Forests	45,302	11,282	10,927	14,993	**82,504**
Indochina Mangroves	-	-	-	12,339	**12,339**

All ecoregions of the LMB have been adversely affected by human activities and only have a portion of their natural habitat remaining. In some cases this habitat consists of isolated remnants (e.g. Southern Annamites Montane Rain Forests) while in other cases there are still fairly large areas of contiguous habitat in place (e.g. South-eastern Indochina Dry Evergreen Forests). Using forest cover (not including plantation forests) as an indicator of natural habitat remaining, the average remaining forest cover of all 14 ecoregions in 2010 was 47 per cent. In total for the whole LMB the remaining forest cover across all ecoregions was 41 per cent. Between 2003 and 2010 forest cover declined in ten ecoregions, remained the same in two and increased in two (Table 3.5). Taken together all 14 ecoregions lost an average of 12 per cent of forested area between 2003 and 2010 (MRC, 2011b).

The area of each ecoregion which is under some form of protected area management ranges from zero to 54 per cent (Table 3.5). The Northern Thailand-Laos Moist Deciduous Forests is the least protected (<1%) and the Cardamom Mountains Rainforest is the most protected (54%). There are, however, a range of different protection regimes in place (across all IUCN categories and beyond) allowing for different types of activities to occur, and regardless of the legal status management and enforcement is problematic in many places. Shifting cultivation, hunting and unsustainable harvest of wildlife and other non-timber forest products are reported as ongoing threats to habitat and biodiversity in many of the protected areas across the LMB.

Table 3.5: Summary of area of forest cover and percentage change between 2003 and 2010 and overall ecoregion status.

Ecoregion	Area in the LMB (km^2)	Forest cover 2003 (%)	Forest cover 2010 (%)	Change 2003-2010 (%)	Area protected (%)	Status[15]
Cardamom mountains rainforest	16,688	81	57	-24	54	Relatively stable/Intact
Kayah-Karen montane rainforests	4,555	71	57	-14	44	Relatively stable/Intact
Luang Prabang montane rainforests	57,435	83	60	-23	16	Vulnerable
Northern annamites rain forest	35,709	82	70	-12	27	Relatively stable/Intact
Northern Indochina subtropical forests	56,130	89	58	-31	19	Vulnerable
Northern Khorat Plateau Moist Deciduous Forests	16,799	33	18	-15	5	Critical/Endangered
Northern Thailand-Laos Moist Deciduous Forests	11,622	88	49	-39	<1	Vulnerable
Northern Vietnam Lowland Rain Forests	163	100	100	0	7	Critical/Endangered
Southern Annamites Montane Rain Forests	24,034	80	75	-5	30	Vulnerable
Tonle Sap Freshwater Swamp Forests	25,768	1	14	+13	13	Vulnerable
Tonle Sap-Mekong Peat Swamp Forests	21,691	3	6	+3	3	Critical/Endangered
Central Indochina Dry Forests	253,147	35	29	-6	11	Vulnerable
South-eastern Indochina Dry Evergreen Forests	82,504	70	56	-14	29	Critical/Endangered
Indochina Mangroves	12,339	9	9	0	10	Critical/Endangered

Only three of 14 ecoregions are assessed as relatively stable/intact (WWF, 2015). Six are considered vulnerable and five are Critical/Endangered (Northern Khorat Plateau Moist Deciduous Forests, Northern Vietnam Lowland Rain Forests, Tonle Sap-Mekong Peat Swamp Forests, South-eastern Indochina Dry Evergreen Forests and the Indochina Mangroves).

Landcover provides insight into human uses of the landscape as well as natural features. Although landcover is sometimes considered synonymous with land use, it is not. How land is used can be different from its category, such as the case of suburban areas with built-up cover in the form of roads and houses that are mixed with paddy fields. This mixed-use of the landscape, such as within the one square kilometre grid in Figure 3.8, is not captured by the landcover type assigned.

Monitoring of landcover change in the LMB—which can be an indirect indicator of human use—provides insight into landscape level dynamics. A good example of this is the disappearance of crops in the region around Luang Prabang in northern Lao PDR. Around 50 per cent of the LMB consisted of forest cover in 2003, a decrease of around 35 per cent from 1993 and 1997. According to the UN Development Program (UNDP, 2013), in 2013 Lao PDR was 40 per cent forested and the rate of forest loss has slowed (Figure 3.83). Figure 3.8(a) shows the distribution of landcover in 1993. In addition to the extent of field crops around Luang Prabang, note the extent of the shrubland cover in northern Lao PDR. However, by 1997 there is a noticeable increase in shrubland cover in the LMB.

[15] Status determined for WWF, accessed 2015.

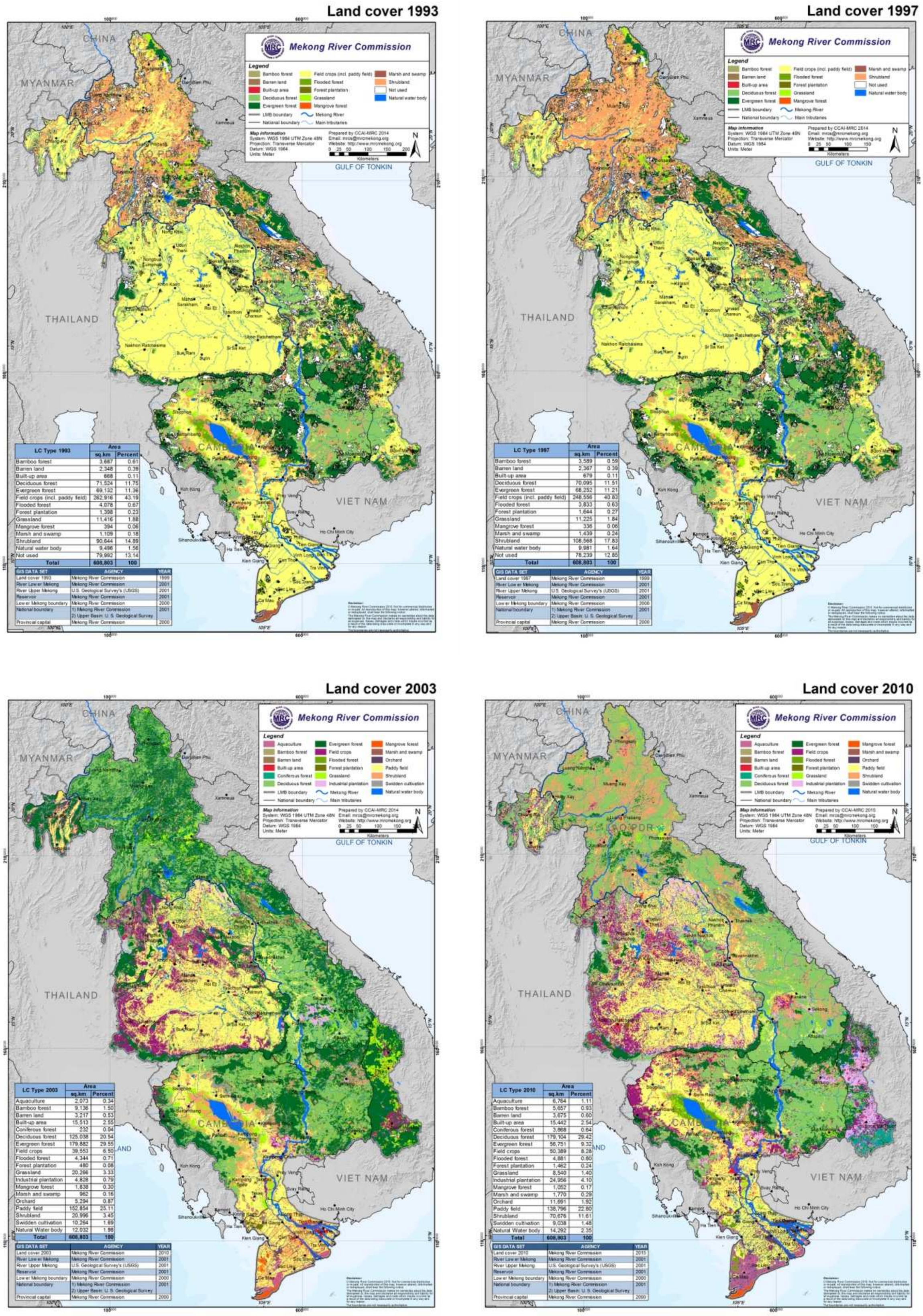


Figure 3.8: Landcover maps of the Lower Mekong Basin for (a) 1993; (b) 1997; (c) 2003; and (d) 2010

Approximately 15 per cent of the LMB was shrubland in 1993, and this increased to approximately 18 per cent by 1997 (Figure 3.8(b)). The majority of the increase in the extent of shrubland appears to be in northern Lao PDR, with field crops replaced by shrubland. This pattern suggests agricultural crops were not being farmed and that the landscape was being permitted to return to a more natural state. For these two ecoregions (High-elevation moist broadleaf forest North Indochina and Low- and mid-elevation moist broadleaf forest) the climax plant community is broadleaf forest. Reviewing the most recent landcover for the area around Luang Prabang shows that by 2003 the majority of the area had become forest cover (Figure 3.8(c)).

A possible explanation for ecoregion change is provided by Yokoyama *et al.* (2006). According to the authors, the Land Forest Allocation Program (LFAP) was initiated by the government of Lao to "stabilize swidden agriculture" in 1996. This was one of several forest conservation programs that designated approved uses of various types of forest land. Although the LFAP was legally enacted in 1996, a pilot implementation was carried out in the northern provinces of Luang Prabang and Xayaburi from 1990 to 1996 (Yokoyama *et al.,* 2006).

Because there was no monitoring and evaluation of the pattern of land use after program implementation, their study consisted of in-depth family surveys in two villages. The LFAP set aside protected forests, conservation forests and regeneration forests that were not to be used for agricultural land use. This story may have unfolded similarly across the provinces, with Kone Kean village farmers restricted to degraded forests consisting of swidden fields and one- to three-year-old fallows, unsuitable for shifting agriculture. Consistent with the transition to forest cover, it was discovered that farmers "let a considerable number of allocated lands lie fallow" (Yokoyama *et al.,* 2006). The overall goal of this government policy was to reclaim forest cover, and it appears from the pattern of landcover change in this area the policy was effective.

Despite the considerable changes that have been observed in vegetation and forests over recent decades, no observed changes in land cover have to-date been attributed to the impacts of climate change. Impacts from human activity such as deforestation and clearing for agricultural use, timber extraction, and infrastructure development are too dominant to be able to discern any additional change as a result of the effects of climate change.

3.2.2 Projected climate change impacts

No projected impact on vegetation and forests has been considered other than those impacts associated with changes in biodiversity and ecosystems including for terrestrial ecoregions and protected areas (section 3.3) and agriculture (section 4.1).

3.3 Biodiversity and ecosystems

Key findings

The contribution of climate change to biodiversity loss and ecosystem degradation to-date has not been determined. However, natural ecosystems, especially wetlands, are already severely degraded and considered highly vulnerable to the effects of climate change. They are projected to be significantly impacted under a range of scenarios, with consequences for species survival and the provision of ecosystem services such as NTFPs, fish and other aquatic resources, and carbon sequestration. Projected climate change impacts vary geographically with different ecoregions more or less impacted under different models. By 2060 many ecoregions will face completely novel bioclimatic conditions and existing protected areas will encompass a much reduced range of bioclimatic conditions. LMB species are highly vulnerable to the effects of climate change with large numbers of fish particularly at risk due to their sensitivity to natural hydrological cues.

3.3.1 Past and current conditions

Land and water resources development during the last century has put increasing pressure on natural resources in the Mekong Basin. Between one third and half of the original forest area in the LMB has been lost, although in Viet Nam the trend has been recently reversed and forest area is growing at 2 per cent per year. The loss of natural wetlands has also been enormous. Already by the year 2003, most of the natural wetlands were lost (Figure 3.10), mostly due to land use changes, including agricultural development. Ongoing developments, such as the expansion of agricultural and urban/industrial areas with year-round flood protection, puts pressure on the remaining wetlands.

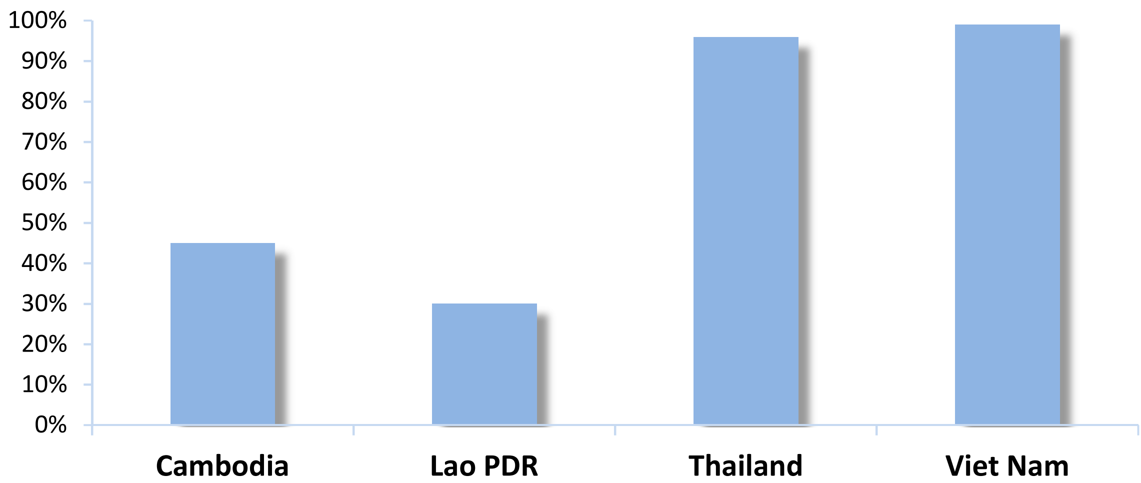


Figure 3.10: Natural wetland loss by 2003 (as % of the original area) in the LMB countries (whole country) (MRC, 2016a).

The total area of wetlands in the Lower Mekong Basin is subject to some uncertainty due partly to different definitions and different delineations of wetland type, and partly due to a lack of up-to-date and available data. MRC has estimated that less than 2 per cent of the original wetland area in the Mekong Delta remains (MRC 2010c). Ringler (2001) reported that wetlands are estimated to cover 6–12 M ha of the entire lower basin. In 2009, MRC reported that there were an estimated 5.25 M ha of *flood-affected* wetlands in the LMB (MRC 2009).

A recent assessment of land cover has been made MRC (2016e) comparing 2003 data with those of 2010 (Section 3.2). From this, the estimated total wetland area in 2010 was 18.8 M ha compared to 19.6 M ha in 2003, representing a reduction of 4 per cent during this period. Splitting this down into "artificial" wetland (being land under paddy field and aquaculture) and "natural" wetland (being flooded forest, inundated grasslands, mangrove, marshes and swamps and water bodies) identifies that "artificial" wetlands have decreased by 8 per cent, whereas "natural" wetlands have apparently increased by 21 per cent. However, within the latter category, the area under mangroves has reduced by a third.

The loss of wetland area combined with infrastructure development, habitat degradation and the introduction of exotic species, overexploitation and illegal wildlife trade, has likely contributed to a considerable loss of species and an increase in the number of threatened species from 327 in 1996 to 1,525 in 2014. Figure 3.11 shows some examples that indicate the that the modelled decline in the abundance of many species has occurred since significant land use changes began some 125 years ago and has accelerated during recent decades as a result of increasing pressures (MRC, 2016b).

Table 3.6: Area variation of land cover in the LMB between 2003 and 2010 (MRC, 2016a).

Land Cover types	in 2003	in 2010	Area Variation of Land cover	Percent change
	Ha	Ha	Ha	%
"Artificial" wetland	17,114,255	15,764,850	-1,349,405	*-8%*
"Natural" wetland	2,516,175	3,038,162	521,987	*21%*
Total wetland area	**19,630,430**	**18,803,012**	**-827,418**	***-4%***

Source: (IKMP 2015); Inundated grasslands taken as sub-category of grasslands with areas based on BDP Scenario Assessments 2010 for Baseline and Definite Future Scenarios respectively

The aforementioned pressures have also led to a modelled reduction in the abundance of many fish species (Figure 3.12). The declines in abundance are most notable since around the 1960's when large areas on the flood plains were brought under (irrigated) agriculture, and more recently due to fishing pressures, urbanization and flood control, agricultural and industrial water use, and loss of riverine connectivity from dams, roads, drains, canals, and barrages. Total capture fisheries yields in the LMB appear to be stable at 1.9 to 2.3 million tons/year (based on 2003 land use data) but the small fish are increasing as a percentage of the catch, both in weight and numbers.

Without effective environmental management, the area of pristine natural wetlands could be reduced further with perhaps only small areas left by 2060, mainly because of expansion of agriculture, urbanization and industrialization. Given the increasing pressure on the natural system, resulting in a loss of natural areas, a loss of connectivity and a deterioration of water quality, the trend in species diversity loss is expected to continue in the future. In the long term, the development of dams and other infrastructure on floodplains will continue to threaten capture fisheries.

Figure 3.11: Modelled historic abundance estimates of selected species (% relative to 2015 (MRC, 2016a; *Source: BIORA progress report no. 2 for Council Study (August 2015)*).

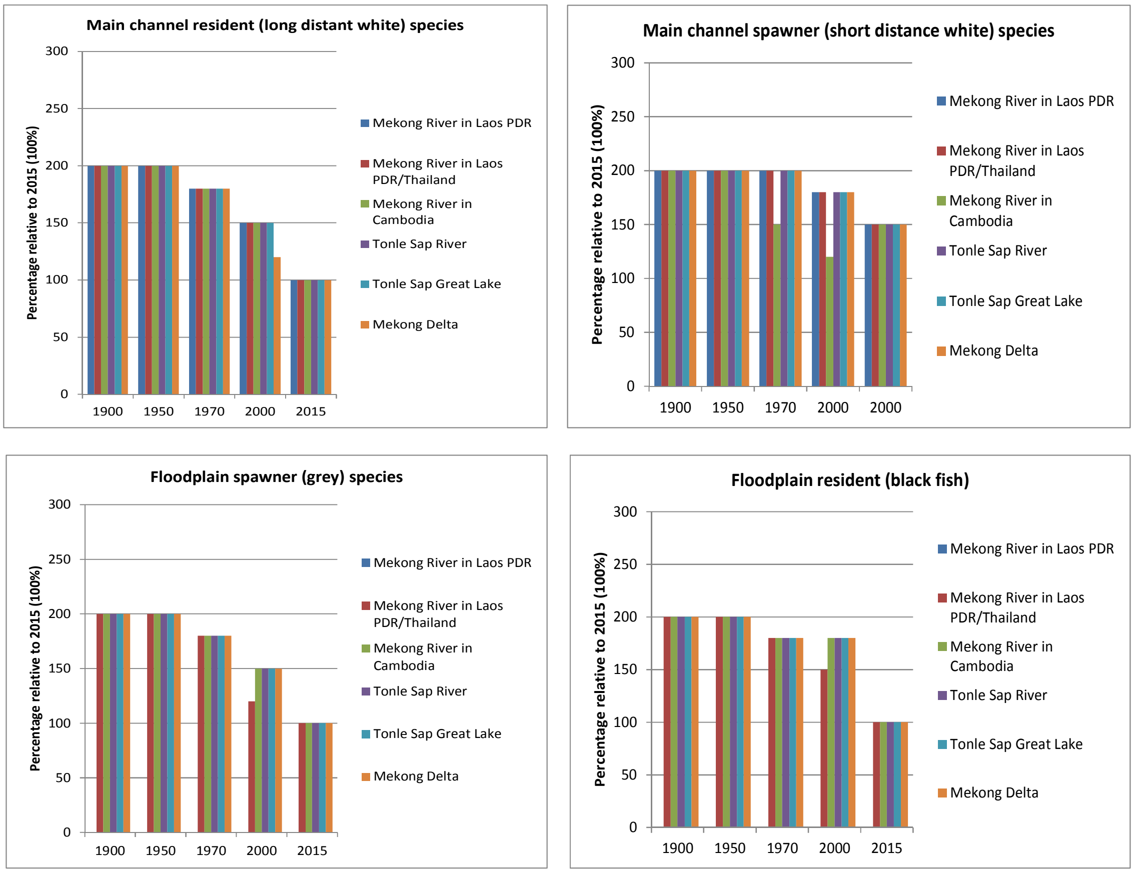


Figure 3.12: Modelled historic abundance estimates of fish species (% relative to 2015) (MRC, 2016a; *Source: BIORA progress report no. 2 for Council Study (August 2015)*).

As identified above, species of the Lower Mekong Basin (LMB) are already under significant pressure. Analysis of the IUCN Red List spatial data indicates a total of one extinct, 31 critically endangered, 62 endangered, and 95 vulnerable species across the LMB (Table 3.7).

Table 3.7: Numbers of LMB species assessed for the IUCN Red List per Red List category (MRC, 2017b).

Red List Category	Amphibians	Birds	Fish	Mammals	Reptiles	Plants
Extinct	-	-	1	-	-	-
Critically endangered	-	10	13	7	1	-
Endangered	4	12	23	20	2	1
Vulnerable	12	19	32	23	8	1
Near Threatened	10	48	22	10	3	4
Data Deficient	35	2	201	23	29	4
Least Concern	83	728	401	193	131	46
Total	**144**	**819**	**693**	**276**	**174**	**56**

Amphibians

Analysis of the Red List spatial data indicated that there are at least 144 amphibian species present in the LMB, of which at least 30 (21%) are endemic to the region. Of the 144 amphibian species known to occur in the LMB 16 (11%) are globally threatened with extinction (Table 3.8), including four Endangered species and 12 Vulnerable species. A further 10 (7%) are Near Threatened. Major threats to LMB amphibians include logging and wood harvesting, affecting 92 (64%) species; non-timber agriculture affecting 90 (62.5%) species; pollution, in the form of agricultural and forestry effluents, affecting 44 (30.5%) species; the development of housing and urban areas affecting 42 (29%) species; and modifications to natural fire regimes affecting 41 (28.5%) species.

Figure 3.13 shows that, in terms of species richness, amphibians are most diverse at the peripheries of the LMB, and in particular along the Viet Nam-Cambodia and Viet Nam-Lao PDR borders, where richness can reach up to 50 (though more typically 31 to 40) species. In the west of the LMB patches exist where amphibian richness reaches 30 to 40 species, while in the majority of the LMB's interior typical amphibian richness is between 21 and 30 species. Amphibian richness is lowest in the south of the LMB where at locations close to the coast between 11 and 15 species are thought to occur.

Birds

Analysis of the Red List spatial data indicates there are at least 819 bird species present in the LMB, of which at least 27 (3%) are endemic to the region. Of the 819 bird species known to occur, 41 (5%) are globally threatened with extinction (Table 3.8), and a further 48 (6%) are Near Threatened. Major threats to LMB birds include non-timber agriculture affecting 100 (12%) species; hunting and collecting of terrestrial animals, affecting 93 (11%) species; logging and wood harvesting, affecting 73 (9%) species; natural systems modifications, in the form of dams and other water management operations, affecting 56 (7%) species; and habitat shifts and alterations resulting from climate change and severe weather, affecting 45 (5.5%) species (not to be confused with the climate change vulnerability assessments presented elsewhere in this report).

Figure 3.13 shows that, in terms of species richness, LMB birds vary widely between locations. Species richness is particularly high in the north of the LMB (particularly in Lao PDR), where as many as 535 species are thought to occur at some locations. As one moves southward bird richness declines, although the total number of species remains high along the eastern periphery of the LMB (predominantly in Lao PDR, but also small areas of Cambodia and Viet Nam) where numbers are typically above 360 species at any given location. Bird richness is lowest in the centre of the LMB (Thailand) where between three and 230 species can occur at any given location. Moving further south into Cambodia and Southern Viet Nam, bird richness increases again to between 260 and 360 species at any given location. The exception to this is a small area in western Cambodia, where up to 400 bird species are thought to occur.

Fish

Analysis of the Red List spatial data indicated that there are at least 692 freshwater fish species present in the LMB, of which at least 159 (23%) are endemic to the region. The Siamese Flat-barbelled Catfish (*Platytropius siamensis*), which was present in the region, was declared extinct in 2013. Of the 692 extant freshwater fish species known to occur in the LMB 68 (10%) are globally threatened with extinction (Table 3.8), and a further 22 (3%) are Near Threatened. Major threats to LMB freshwater fish include pollution, in the form of agricultural and forestry effluents, affecting 359 (52%) species; Fishing and the harvest of aquatic resources, affecting 303 (44%) species; and natural systems modifications, in the form of dams and other water management operations, affecting 286 (41%) species.

Figure 3.13 shows that, in terms of species richness, LMB freshwater fish species are most diverse (up to 108 species at a given location) at locations along, or directly next to, the main channel of the Mekong River. The only exception to this is in the north of the LMB (in Lao PDR) where species numbers drop to around 51 to 60, even on the main river channel. Broadly speaking, numbers of freshwater fish species become lower as one moves further away from the main river channel. At most locations on the eastern, western and northern peripheries of the LMB the number of freshwater fish species present is between zero and 30.

Mammals

Analysis of the Red List spatial data indicated that there are at least 276 mammal species present in the LMB, of which at least 23 (8%) are endemic to the region. Of the 276 mammal species known to occur, 50 (18%) are globally threatened with extinction (Table 3.8), and a further 10 (4%) are Near Threatened. Major threats to LMB mammals include agriculture and aquaculture, in the form of non-timber crops affecting 178 (64%) species, and, to a lesser extent, wood and pulp plantations, affecting 35 (17%) species; the hunting and collecting of terrestrial animals, affecting 134 (49%) species; logging and wood harvesting, affecting 84 (30%) species; and the development of housing and urban areas, affecting 60 (22%) species.

Figure 3.13 shows that, in terms of species richness, LMB mammals are most diverse in the north of the LMB, and in particular in Lao PDR, where between 131 and 160 species are estimated to occur at most locations. Mammal species richness appears to decline as one moves southward across the LMB, although the number of mammal species present remains relatively high (>100 species per grid cell) at the eastern and western peripheries. Mammal species richness is lowest in the far south of the LMB (southern Viet Nam), where the number of species per grid cell is estimated to be 70 or less at all locations.

Reptiles

Analysis of the Red List spatial data provided a list of 174 reptile species known to be present in the LMB, of which nine (5%) are endemic to the region. Of the 174 LMB reptile species that have been assessed for the IUCN Red List, 11 (6%) are globally threatened with extinction (Table 3.8), and a further three (2%) are Near Threatened. Major threats to these reptiles include agriculture and aquaculture, in the form of non-timber crops affecting 107 (61%) species; fishing and the harvest of aquatic resources, affecting 56 (32%) species; logging and wood harvesting, affecting 51 (29%) species; the development of housing and urban areas, affecting 33 (19%) species; and the hunting and collection of animals, also affecting 33 (19%) species.

Figure 3.13 shows that, in terms of species richness, reptiles are most diverse in the southern half of the LMB, and in particular on the eastern and western peripheries, where up to 72 species (of those with available range maps) per grid cell can occur. Across the remainder of the southern LMB, and in small areas in the north (e.g. a small area of Thailand, bordering Lao PDR and Myanmar) numbers are typically between 50 and 57 species per grid cell. Reptile richness appears to be lowest in the far north of the LMB, where as few as 11 species per grid cell are thought to occur. In most of the remainder of the northern LMB numbers of reptile species (of those assessed) typically range between 39 and 49 species.

Plants

Red List assessments of LMB plants are far from comprehensive, and an analysis of the Red List spatial data provided information on a total of only 56 species from 19 families – far from representative of such a floristically diverse region (the Mekong Basin, in its entirety, is estimated to contain around 20,000 plant species[16]. Of these 56 plant species, none are endemic to the LMB, two (3.5%) are globally threatened with extinction (Table 3.8), and a further four (7%) are Near Threatened. Major threats to these plants include logging and wood harvesting, affecting 35 (62.5%) species; marine and freshwater aquaculture, affecting 33 (59%) species; habitat shifts and alterations resulting from climate change and severe weather, affecting 33 (59%) species; the development of housing and urban areas, affecting 32 (57%) species; and agriculture and aquaculture, in the form of non-timber crops affecting 30 (54%) species. Figure 3.13 shows the distribution of plant species assessed for vulnerability to climate change for MRC (2017b).

[16] http://www.mrcmekong.org/topics/environmental-health/

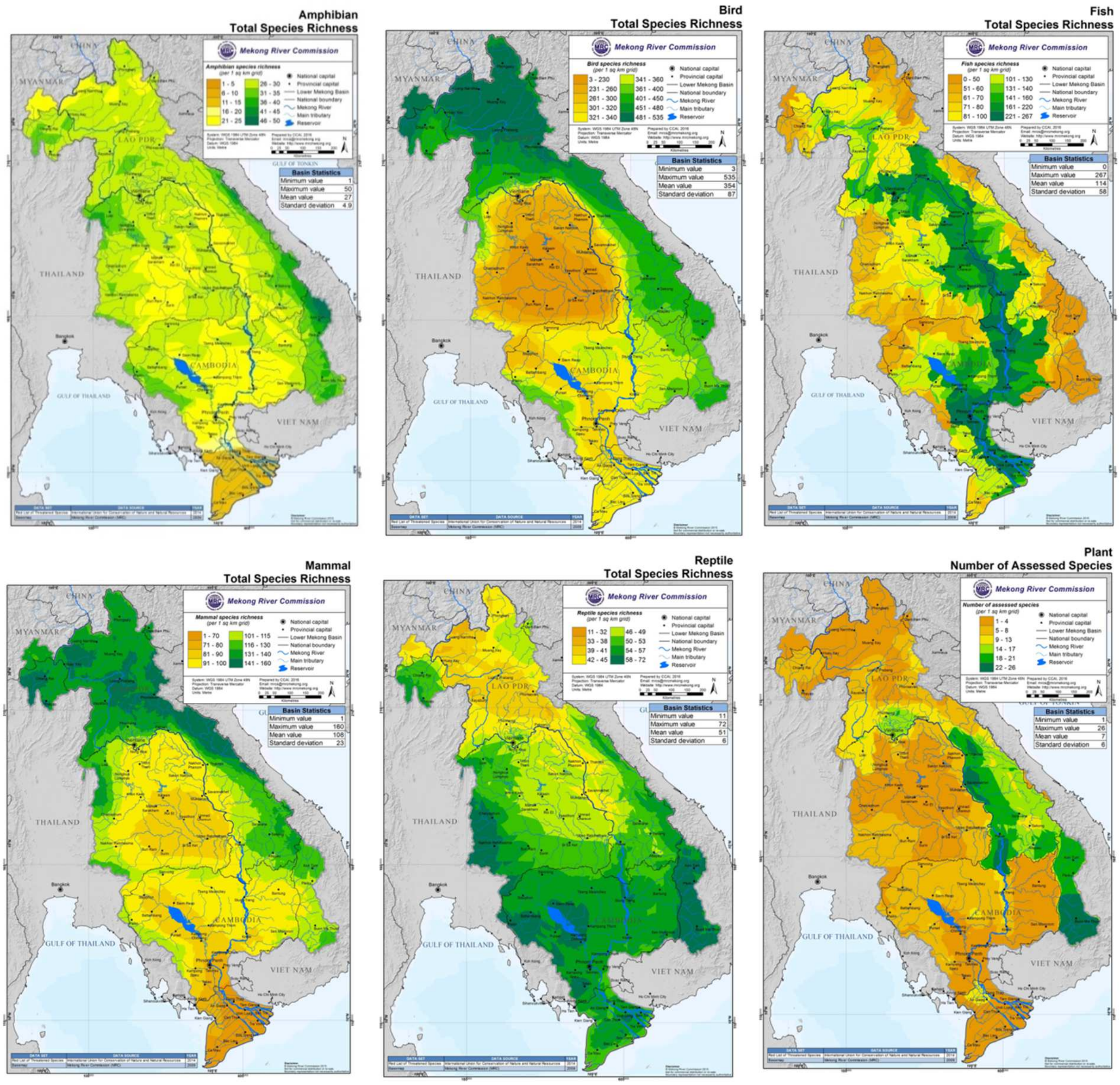


Figure 3.13: Species richness of (a) amphibians; (b) birds; (c) fish; (d) mammals; and (e) reptiles. For plants, the floristic diversity of the Mekong is not reflected in IUCN Red List data and so (f) shows only the plants in the LMB that were assessed for species vulnerability to climate change in this study (MRC, 2017b).

Ecosystem Services

There are a number of important ecosystem services provided by the ecosystems of the LMB (MRC, 2003; 2010d). Across forest, wetland and mangrove ecosystems these include (WWF, 2013):

- Timber harvesting
- Local use of non-timber forest products
- Watershed protection
- Carbon Sequestration
- Harvest of aquatic products (including fish and Other Aquatic Animals (OAA))
- Water quality and flow services (including flood mitigation)
- Coastal protection
- Tourism and recreation

WWF (2013) undertook an economic valuation of the ecosystem services across four Member Countries as well as describing previous work to do the same within each country. However, they find that there is a lack of information on almost all ecosystem values in the region, including most ecosystem types and categories of ecosystem services. Talberth (2015) produced a report on valuing ecosystem services within each LMB country and identified a number of examples of previous valuation studies that had been undertaken. While far from comprehensive, these examples provide an indication of the considerable value of ecosystem services across all Member Countries.

Although there has already been significant change to habitats and biodiversity across the 14 ecoregions of the LMB there are a large number of threats that continue to put these ecosystems under pressure. These include:

- Agricultural expansion and shifting cultivation
- Development of water resources including for hydropower
- Other development activities including for industrial plantations, mining, industry and urban areas with attendant requirements for roads and labour settlements
- Illegal logging and hunting and unstainable harvest of wildlife and other non-timber forest products
- Pollution including from agricultural runoff
- Expansion of invasive species
- Forest fire, including those deliberately lit
- Climate change, impacting on temperatures and rainfall, and water availability

Overall, agriculture is the pre-dominant means of livelihood in all ecoregions, supported by the harvest of fish and other aquatic animals particularly in the Tonle Sap Freshwater Swamp Forests. The hunting of wildlife and harvest of other non-timber forest products for consumption and trade is also an important supplement to many people's livelihoods. People in urban and built-up areas engaged in service industries, particularly retail.

Despite the significant changes that have been observed for biodiversity and ecosystems across the LMB, the contribution of climate change to the loss of biodiversity and ecosystem degradation has to-date not been determined. Previous studies have focused almost exclusively on identifying the potential impacts of climate change on habitats and species under different future scenarios rather than seeking to attribute past change to climate change that is already occurring.

3.3.2 Projected climate change impacts

An assessment of climate change impacts on ecoregions and habitats was undertaken using a modelling approach based on a statistically derived environmental stratification (Metzger *et al.*, 2013; Zomer *et al.*, 2014; 2015a; 2015b) which was used to predict and understand the nature and magnitude of projected changes in the spatial distribution of bioclimatic conditions across the Lower Mekong Basin by the years 2030 and 2060. To produce the derived LMB dataset, a maximum likelihood analysis was applied using the SimClim (1995) Baseline dataset of climatic variables to reproduce the original Global Environmental Stratification (GEnS; Metzger *et al*., 2013) using the BioClim_EnS tool, based on the methodology described in Zomer *et al*. (2014; 2015). The baseline was compiled from a dataset of interpolated weather station data averaged over 30 years, from 1980 to 2010. The derived LMB dataset was considered to be of high accuracy in comparison to the original Global Environmental Stratification (MRC, 2017a; Zomer, 2016).

The bioclimatic variables assessed for change using three Resource Concentration Pathways (RCP) and three scenario models were:

- mean annual temperature
- mean annual precipitation
- annual mean Potential Evapotranspiration (PET)
- an Aridity-Wetness Index (AWI)

These variables are understood to be important for growing conditions of plants, both natural vegetation and crops supporting peoples' livelihoods. The PET is a measure of the total potential amount of transpiration (from plants) and evaporation (from soil and plant canopy) that can be expected under existing or projected temperature and relative humidity conditions. AWI is an integrative measure used to assess the moisture (precipitation) available for plant growth (i.e. after evapotranspiration). It is the ratio of mean annual precipitation to the mean annual PET, with a higher AWI indicating more moisture is available for plant growth. For further information on PET and AWI see Zomer *et al.* (2008); MRC (2017a) and Zomer (2016) for their use in the MRC's basin-wide assessment of climate change impacts on biodiversity and ecosystems.

Projected changes in mean annual temperature across ecoregions are illustrated in Figure 3.14. Increases range from 0.4˚C to 1.5˚C by 2030 and 0.3˚C to 3.2˚C by 2060 under the wetter overall scenario with the variation due to the choice of emissions scenario – the higher the emissions scenario, the greater the temperature increase (MRC, 2017a). By 2060 the largest increases in temperature are projected to occur in the Kayah-Karen Montane Rainforests, the Luang Prabang Montane Rain Forests, the Northern Khorat Plateau Moist Deciduous Forests, and the Northern Thailand-Laos Moist Deciduous Forests.

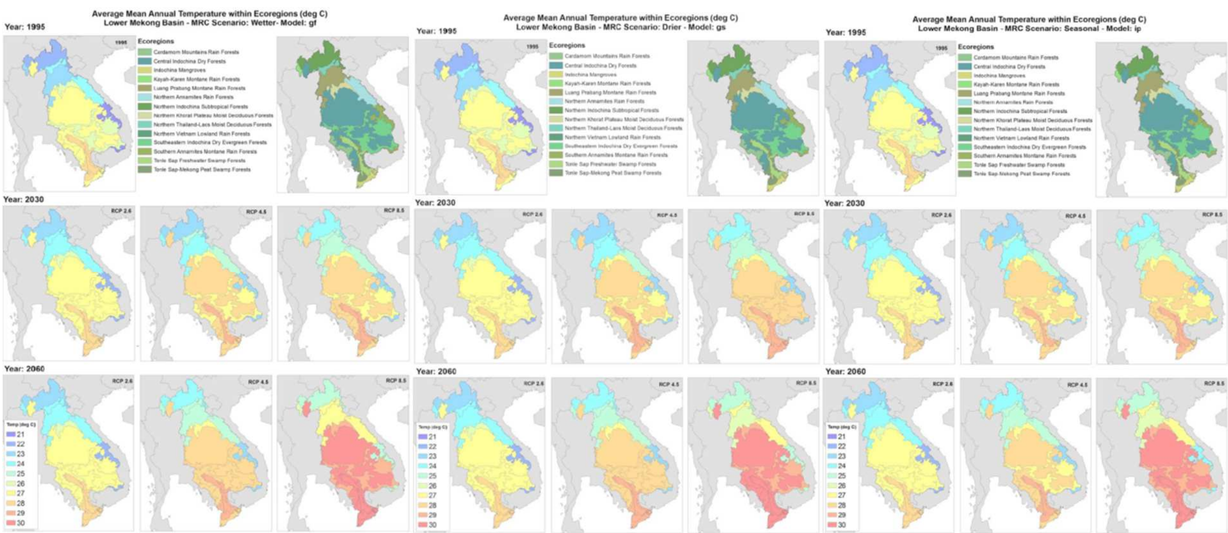


Figure 3.14: Average annual Temperature within each ecoregion under baseline conditions and as projected for 2030 and 2060 across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by (a) the wetter scenario model; (b) the drier scenario model; and (c) the increased seasonality model (MRC, 2017a; Zomer, 2016).

Under the drier overall scenario and the increased seasonality scenario, increases in temperature are similar to the wetter overall scenario. However, the largest increases by 2060 occur in different ecoregions. In the driver overall scenario, the largest increases occur in the Cardamom Mountains Rain Forests, Central Indochina Dry Forests and the Tonle Dap Freshwater Swamp Forests. In the increased seasonality scenario the largest increases occur in the Kayah-Karen Montane Rainforests, the Northern Indochina Subtropical Forests and the Northern Thailand-Laos Moist Deciduous Forests.

Projected changes in mean annual precipitation across ecoregions are illustrated in Figure 3.15. Increases range from 27 mm to 189 mm by 2030 and 20 mm to 395 mm by 2060 under the wetter overall scenario with the variation due to the choice of emissions scenario – the higher the emissions scenario, the greater the annual precipitation increase (MRC, 2017a). By 2060 the largest increases in precipitation are projected to occur in the Northern Khorat Plateau Moist Deciduous Forests and the Northern Indochina Subtropical Forests.

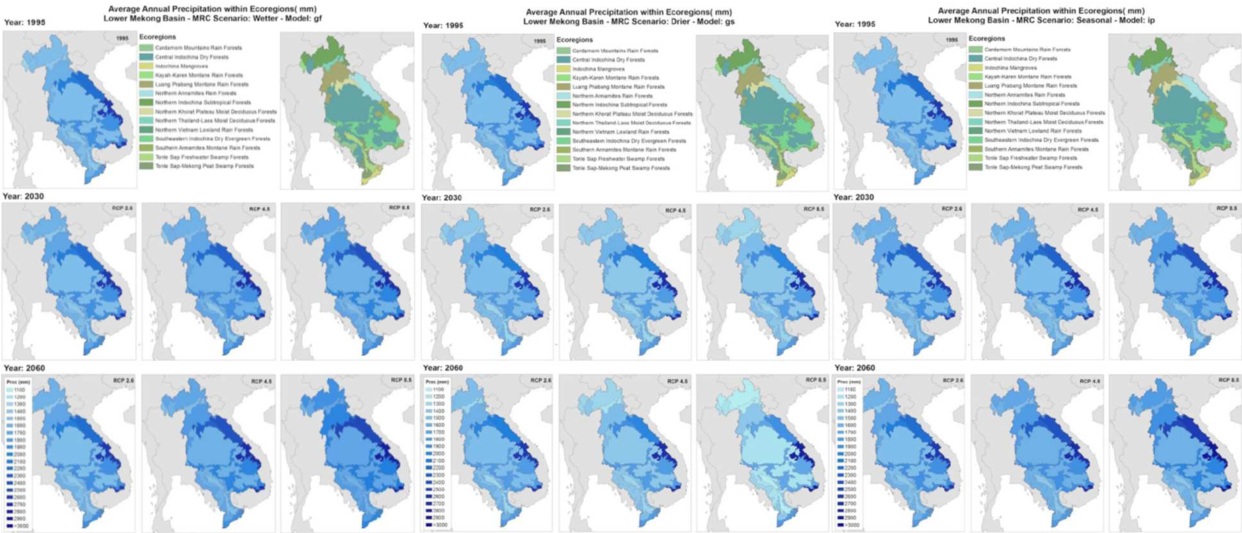


Figure 3.15: Average annual Precipitation within each ecoregion under baseline conditions and as projected for 2030 and 2060 across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by (a) the wetter scenario model; (b) the drier scenario model; and (c) the increased seasonality model (MRC, 2017a; Zomer, 2016).

Under the drier overall scenario mean annual precipitation change ranges from a decline of -214 mm to an increase of 110 mm by 2030 and a decline of -462 mm to an increase of 258 mm by 2060 (MRC, 2016e). Increases in precipitation occur in the Northern Vietnam Lowland Rain Forests and the Southern Annamites Montane Rain Forests but decline in all other ecoregions. The most significant decline by 2060 occurs in the Northern Indochina Subtropical Forests ecoregion.

Under the increased seasonality scenario, mean annual precipitation change ranges from a decline of -45 mm to an increase of 217 mm by 2030 and a decline of -91 mm to an increase of 459 mm by 2060 (MRC, 2017a). Decreases in precipitation occur in the Cardamom Mountains Rain Forests and the Indochina Mangroves but increase in all other ecoregions. The most significant increases in mean annual precipitation occur in the Northern Vietnam Lowland Rain Forests and the Northern Khorat Plateau Moist Deciduous Forests.

Projected changes in Potential Evapotranspiration across ecoregions are illustrated in Figure 3.16. Increases range from 11.1 mm to 59.56 mm by 2030 and 9.1 mm to 128.56 mm by 2060 under the wetter overall scenario with the variation due to the choice of emissions scenario – the higher the emissions scenario, the greater the PET increase (MRC, 2017a). By 2060 the largest increases in PET are projected to occur in the Luang Prabang Montane Rain Forests and the Northern Khorat Plateau Moist Deciduous Forests.

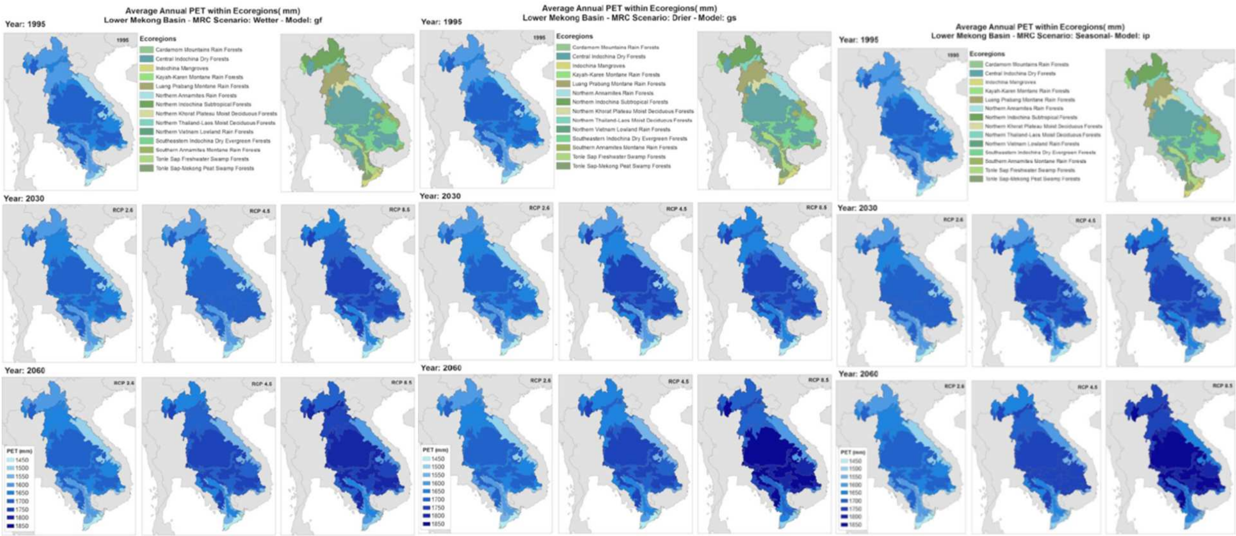


Figure 3.16: Average annual PET within each ecoregion under baseline conditions and as projected for 2030 and 2060 across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by (a) the wetter scenario model; (b) the drier scenario model; and (c) the increased seasonality model (MRC, 2017a; Zomer, 2016).

Under the drier overall scenario PET increases range from 12.1 mm to 66.86 mm by 2030 and from 9.1 mm to 143.86 mm by 2060 (MRC, 2016e). By 2060 the largest increases in PET are projected to occur in the Cardamom Mountains Rain Forests and the Central Indochina Dry Forests.

Under the increased seasonality scenario, PET increases range from 19 mm to 80 mm by 2030 and from 14 mm to 173 mm by 2060 (MRC, 2017a). By 2060 the largest increases in PET are projected to occur in the Central Indochina Dry Forests and the Northern Vietnam Lowland Rain Forests.

Projected changes in AWI across ecoregions are illustrated in Figure 3.17. Increases range from 0.00 to 0.08 by 2030 and 90.00 to 0.16 by 2060 under the wetter overall scenario with the variation due to the choice of emissions scenario – the higher the emissions scenario, the greater the AWI increase (MRC, 2017a). By 2060 the largest increases in AWI are projected to occur in the Northern Indochina Subtropical Forests and the Northern Thailand-Laos Moist Deciduous Forests. Under the drier overall scenario AWI changes range from a decrease of -0.17 to an increase of 0.02 by 2030 and a decrease of -0.35 to an increase of 0.06 by 2060. By 2060 increases in AWI occur in the Northern Vietnam Lowland Rain Forests and the Southern Annamites Montane Rain Forests and decrease in all other ecoregions. The largest decrease in AWI occurs in the Northern Indochina Subtropical Forests.

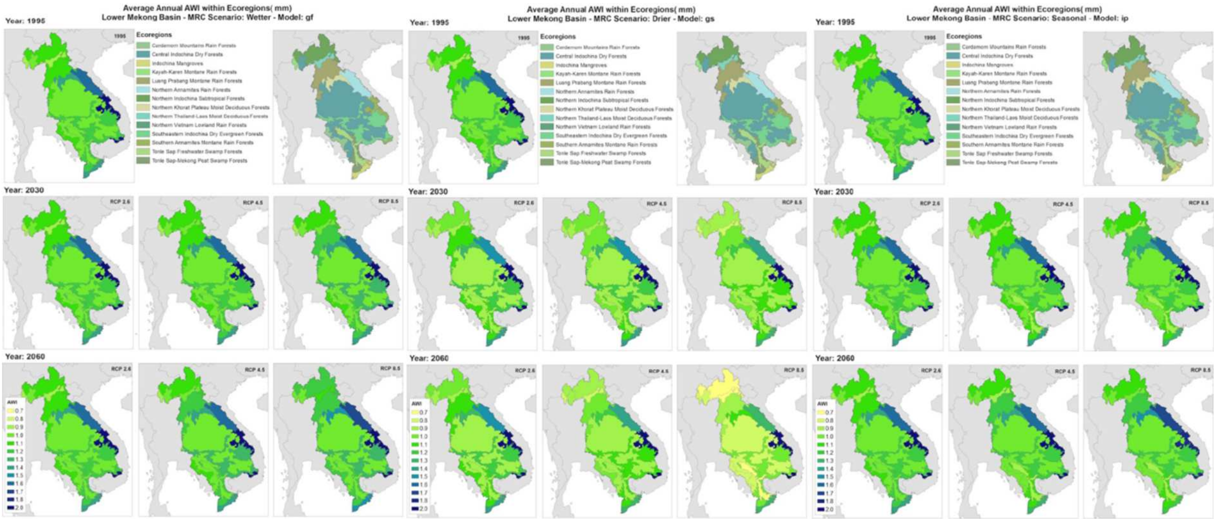


Figure 3.17: Average annual AWI within each ecoregion under baseline conditions and as projected for 2030 and 2060 across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by (a) the wetter scenario model; (b) the drier scenario model; and (c) the increased seasonality model (MRC, 2017a; Zomer, 2016).

Under the increased seasonality scenario AWI changes range from a decrease of -0.08 to an increase of 0.08 by 2030 and a decrease of -0.16 to an increase of 0.15 by 2060 (MRC, 2017a). By 2060 increases in AWI occur in seven ecoregions and decreases occur in the other seven. The largest decrease in AWI occurs in the Indochina Mangroves and the largest increase occurs in Kayah-Karen Montane Rain Forests.

Shift in bioclimatic conditions within Ecoregions

Figures 3.18 and 3.19 illustrate the proportion of each ecoregion as well as the overall area that is projected to shift to a different bioclimatic zone by 2030 and by 2060 under the three emissions pathways and three model scenarios. Excluding the Northern Viet Nam Lowland Rain Forests given its small size, the proportion of the area of each ecoregion that shifts to a different bioclimatic zone by 2030 ranges from 2.3% to 24% for RCP2.6 and from 8.9% to 60% for RCP8.5 under the overall wetter scenario; from 3.9% to 21% for RCP2.6 and from 19.4% to 63.2% for RCP8.5 under the overall drier scenario; and from 2.4% to 22.4% for RCP2.6 and from 20.9% to 87.8% for the increased seasonality scenario (MRC, 2017a).

By 2060, these figures have not moved much under the lowest emissions scenario (RCP2.6) but have increased significantly for the higher emissions scenarios (MRC, 2017a). The areal shift in bioclimatic conditions ranges from 1.1% to 17.5% for RCP 2.6 and from 48% to 100% for RCP8.5 under the overall wetter scenario; from 1.8% to 18% for RCP2.6 and from 51.9% to 100% for RCP8.5 under the overall drier scenario; and from 1.2% to 17.7% for RCP2.6 and from 28.4% to 100% for RCP8.5 under the increased seasonality scenario. What this means in essence is that if emissions follow the lower trajectory then the most significant impacts on ecoregions are likely to be felt in the near future and then remain relatively stable, while if emissions follow the highest scenario then very significant impacts will be felt in the near term and these will continue to worsen as time proceeds.

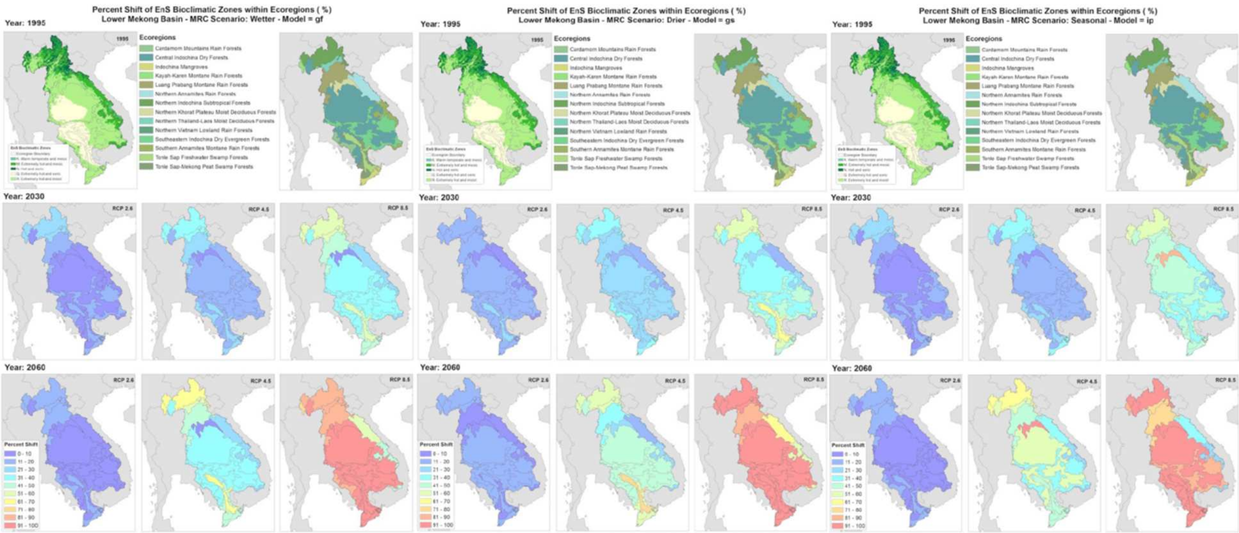


Figure 3.18: Proportion of each ecoregion shifting to a different bioclimatic zone under baseline conditions and as projected for 2030 and 2060 across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by (a) the wetter scenario model; (b) the drier scenario model; and (c) the increased seasonality model (MRC, 2017a; Zomer, 2016).

Different ecoregions are affected differently under different scenarios (MRC, 2017a). For instance, by 2060 under the wetter overall scenario the most impacted ecoregions are the Tonle Sap Freshwater Swamp Forests, the Tonle Sap-Mekong Peat Swamp Forests, the Indochina Mangroves and the Northern Khorat Plateau Moist Deciduous Forests; under the overall drier scenario in addition to the first of those three are the Northern Thailand-Laos Moist Deciduous Forests, the Northern Indochina subtropical Forests, the Kayah-Karen Montane Rain Forests, Cardamom Mountains Rain Forests, the Central Indochina Dry Forests and the Southeastern Indochina Dry Evergreen Forests are all projected to experience a shift in bioclimatic conditions over 90% of their area.

The largest ecoregion by far, the Central Indochina Dry Forests, which covers more than 40 per cent of the area of the Lower Mekong Basin, by 2060, experiences a shift in bioclimatic conditions by between 7.6% and 96.7% under the overall wetter scenario, between 10.9% and 97.4% under the overall drier scenario, and between 7.7% and 96.6% under the increased seasonality scenario. The projected amount is more dependent on the emissions scenario than the choice of GCM. The higher the emissions scenario, the greater the area that experiences a shift in bioclimatic conditions across the Basin, with more significant changes evident by 2060 compared to 2030 (MRC, 2017a).

In almost all scenarios it is the Northern Annamites Rain Forests and the Southern Annamites Montane Rain Forests that are least impacted. Under the overall drier scenario, apart from the Northern Vietnam Lowland Rain Forests, the Northern Annamites Rain Forests and the Southern Annamites Montane Rain Forests, all other ecoregions have a minimum of 86% shift in bioclimatic conditions by 2060 under emissions scenario RCP8.5.

Overall the proportional shifts are greater in the wetter and drier overall scenarios. However, the projected shifts in bioclimatic conditions are still very significant for the increased seasonality scenario (MRC, 2017a).

Percent Change - EnS Zones - Model: Wetter (gf)

Projected Year: 2030 EcoRegion	EcoRegion Area km²	% of total	RCP 2.6 km²	%	RCP 4.5 km²	%	RCP 8.5 km²	%
Cardamom Mountains Rain Forests	16,697	2.7	2,266	13.6	3,501	21.0	5,252	31.5
Central Indochina Dry Forests	253,112	40.7	23,663	9.3	33,869	13.4	78,063	30.8
Indochina Mangroves	12,338	2.0	1,936	15.7	3,379	27.4	5,344	43.3
Kayah-Karen Montane Rain Forests	5,022	0.8	1,203	24.0	2,003	39.9	3,015	60.0
Luang Prabang Montane Rain Forests	57,227	9.2	7,652	13.4	14,606	25.5	26,148	45.7
Northern Annamites Rain Forests	35,375	5.7	3,295	9.3	5,383	15.2	8,256	23.3
Northern Indochina Subtropical Forests	60,796	9.8	13,682	22.5	23,134	38.1	36,271	59.7
Northern Khorat Plateau Moist Deciduous Forests	16,803	2.7	379	2.3	1,161	6.9	1,492	8.9
Northern Thailand-Laos Moist Deciduous Forests	11,606	1.9	2,470	21.3	4,025	34.7	5,969	51.4
Northern Vietnam Lowland Rain Forests	142	0.0	-	0.0	-	0.0	-	0.0
Southeastern Indochina Dry Evergreen Forests	82,369	13.2	9,283	11.3	15,152	18.4	28,494	34.6
Southern Annamites Montane Rain Forests	23,774	3.8	1,733	7.3	2,953	12.4	5,017	21.1
Tonle Sap Freshwater Swamp Forests	25,735	4.1	4,788	18.6	6,345	24.7	14,388	55.9
Tonle Sap-Mekong Peat Swamp Forests	21,604	3.5	1,650	7.6	3,371	15.6	9,228	42.7

Projected Year: 2060 EcoRegion	EcoRegion Area km²	% of total	RCP 2.6 km²	%	RCP 4.5 km²	%	RCP 8.5 km²	%
Cardamom Mountains Rain Forests	16,697	2.7	1,805	10.8	5,501	32.9	14,022	84.0
Central Indochina Dry Forests	253,112	40.7	19,143	7.6	92,008	36.4	244,847	96.7
Indochina Mangroves	12,338	2.0	1,382	11.2	5,434	44.0	12,338	100.0
Kayah-Karen Montane Rain Forests	5,022	0.8	931	18.5	3,086	61.4	3,630	72.3
Luang Prabang Montane Rain Forests	57,227	9.2	5,784	10.1	27,142	47.4	48,747	85.2
Northern Annamites Rain Forests	35,375	5.7	2,672	7.6	8,646	24.4	19,830	56.1
Northern Indochina Subtropical Forests	60,796	9.8	10,632	17.5	37,334	61.4	50,981	83.9
Northern Khorat Plateau Moist Deciduous Forests	16,803	2.7	190	1.1	1,460	8.7	16,398	97.6
Northern Thailand-Laos Moist Deciduous Forests	11,606	1.9	1,955	16.8	6,100	52.6	9,315	80.3
Northern Vietnam Lowland Rain Forests	142	0.0	-	0.0	-	0.0	-	0.0
Southeastern Indochina Dry Evergreen Forests	82,369	13.2	7,288	8.8	31,737	38.5	74,929	91.0
Southern Annamites Montane Rain Forests	23,774	3.8	1,356	5.7	5,223	22.0	11,420	48.0
Tonle Sap Freshwater Swamp Forests	25,735	4.1	3,895	15.1	16,456	63.9	25,735	100.0
Tonle Sap-Mekong Peat Swamp Forests	21,604	3.5	1,281	5.9	9,744	45.1	21,591	99.9

Percent Change - EnS Zones - Model: Drier (gs)

Projected Year: 2030 EcoRegion	EcoRegion Area km²	% of total	RCP 2.6 km²	%	RCP 4.5 km²	%	RCP 8.5 km²	%
Cardamom Mountains Rain Forests	16,697	2.7	3,294	19.7	5,249	31.4	7,911	47.4
Central Indochina Dry Forests	253,112	40.7	35,721	14.1	53,793	21.3	100,276	39.6
Indochina Mangroves	12,338	2.0	2,393	19.4	4,341	35.2	6,173	50.0
Kayah-Karen Montane Rain Forests	5,022	0.8	924	18.4	1,549	30.8	2,485	49.5
Luang Prabang Montane Rain Forests	57,227	9.2	6,187	10.8	12,297	21.5	21,369	37.3
Northern Annamites Rain Forests	35,375	5.7	2,631	7.4	4,242	12.0	6,850	19.4
Northern Indochina Subtropical Forests	60,796	9.8	11,270	18.5	20,034	33.0	33,808	55.6
Northern Khorat Plateau Moist Deciduous Forests	16,803	2.7	662	3.9	2,008	12.0	4,412	26.3
Northern Thailand-Laos Moist Deciduous Forests	11,606	1.9	2,085	18.0	3,437	29.6	6,466	55.7
Northern Vietnam Lowland Rain Forests	142	0.0	-	0.0	-	0.0	-	0.0
Southeastern Indochina Dry Evergreen Forests	82,369	13.2	13,094	15.9	20,228	24.6	33,908	41.2
Southern Annamites Montane Rain Forests	23,774	3.8	1,982	8.3	3,365	14.2	5,746	24.2
Tonle Sap Freshwater Swamp Forests	25,735	4.1	5,415	21.0	6,723	26.1	16,253	63.2
Tonle Sap-Mekong Peat Swamp Forests	21,604	3.5	2,386	11.0	4,499	20.8	11,322	52.4

Projected Year: 2060 EcoRegion	EcoRegion Area km²	% of total	RCP 2.6 km²	%	RCP 4.5 km²	%	RCP 8.5 km²	%
Cardamom Mountains Rain Forests	16,697	2.7	2,598	15.6	8,160	48.9	16,497	98.8
Central Indochina Dry Forests	253,112	40.7	27,479	10.9	109,905	43.4	246,532	97.4
Indochina Mangroves	12,338	2.0	1,847	15.0	6,338	51.4	12,338	100.0
Kayah-Karen Montane Rain Forests	5,022	0.8	708	14.1	2,556	50.9	4,970	99.0
Luang Prabang Montane Rain Forests	57,227	9.2	4,670	8.2	22,248	38.9	49,694	86.8
Northern Annamites Rain Forests	35,375	5.7	2,075	5.9	7,075	20.0	23,007	65.0
Northern Indochina Subtropical Forests	60,796	9.8	8,643	14.2	34,907	57.4	60,523	99.6
Northern Khorat Plateau Moist Deciduous Forests	16,803	2.7	297	1.8	4,594	27.3	15,400	91.7
Northern Thailand-Laos Moist Deciduous Forests	11,606	1.9	1,625	14.0	6,745	58.1	11,602	100.0
Northern Vietnam Lowland Rain Forests	142	0.0	-	0.0	-	0.0	-	0.0
Southeastern Indochina Dry Evergreen Forests	82,369	13.2	10,333	12.5	36,428	44.2	76,590	93.0
Southern Annamites Montane Rain Forests	23,774	3.8	1,552	6.5	5,966	25.1	12,329	51.9
Tonle Sap Freshwater Swamp Forests	25,735	4.1	4,623	18.0	18,571	72.2	25,735	100.0
Tonle Sap-Mekong Peat Swamp Forests	21,604	3.5	1,812	8.4	12,294	56.9	21,602	100.0

Percent Change - EnS Zones - Model: Seasonal (ip)

Projected Year: 2030 EcoRegion	EcoRegion Area km²	% of total	RCP 2.6 km²	%	RCP 4.5 km²	%	RCP 8.5 km²	%
Cardamom Mountains Rain Forests	16,697	2.7	2,607	15.6	4,158	24.9	6,416	38.4
Central Indochina Dry Forests	253,112	40.7	24,602	9.7	37,601	14.9	115,979	45.8
Indochina Mangroves	12,338	2.0	1,993	16.2	3,711	30.1	5,825	47.2
Kayah-Karen Montane Rain Forests	5,022	0.8	1,126	22.4	1,890	37.6	2,954	58.8
Luang Prabang Montane Rain Forests	57,227	9.2	7,671	13.4	14,943	26.1	27,163	47.5
Northern Annamites Rain Forests	35,375	5.7	2,573	7.3	5,640	15.9	13,537	38.3
Northern Indochina Subtropical Forests	60,796	9.8	13,481	22.2	22,832	37.6	36,143	59.4
Northern Khorat Plateau Moist Deciduous Forests	16,803	2.7	395	2.4	1,307	7.8	14,748	87.8
Northern Thailand-Laos Moist Deciduous Forests	11,606	1.9	2,376	20.5	3,844	33.1	5,774	49.8
Northern Vietnam Lowland Rain Forests	142	0.0	-	0.0	-	0.0	-	0.0
Southeastern Indochina Dry Evergreen Forests	82,369	13.2	9,086	11.0	14,464	17.6	26,663	32.4
Southern Annamites Montane Rain Forests	23,774	3.8	2,420	10.2	4,094	17.2	4,957	20.9
Tonle Sap Freshwater Swamp Forests	25,735	4.1	4,884	19.0	6,516	25.3	9,694	37.7
Tonle Sap-Mekong Peat Swamp Forests	21,604	3.5	1,742	8.1	3,909	18.1	8,754	40.5

Projected Year: 2060 EcoRegion	EcoRegion Area km²	% of total	RCP 2.6 km²	%	RCP 4.5 km²	%	RCP 8.5 km²	%
Cardamom Mountains Rain Forests	16,697	2.7	2,121	12.7	6,571	39.4	15,128	90.6
Central Indochina Dry Forests	253,112	40.7	19,499	7.7	128,507	50.8	244,396	96.6
Indochina Mangroves	12,338	2.0	1,425	11.5	5,953	48.2	12,338	100.0
Kayah-Karen Montane Rain Forests	5,022	0.8	890	17.7	3,028	60.3	4,444	88.5
Luang Prabang Montane Rain Forests	57,227	9.2	5,806	10.1	27,906	48.8	43,919	76.7
Northern Annamites Rain Forests	35,375	5.7	2,042	5.8	13,592	38.4	13,893	39.3
Northern Indochina Subtropical Forests	60,796	9.8	10,446	17.2	37,177	61.2	56,659	93.2
Northern Khorat Plateau Moist Deciduous Forests	16,803	2.7	210	1.2	15,482	92.1	16,735	99.6
Northern Thailand-Laos Moist Deciduous Forests	11,606	1.9	1,879	16.2	5,914	51.0	8,807	75.9
Northern Vietnam Lowland Rain Forests	142	0.0	-	0.0	-	0.0	-	0.0
Southeastern Indochina Dry Evergreen Forests	82,369	13.2	7,089	8.6	29,554	35.9	69,046	83.8
Southern Annamites Montane Rain Forests	23,774	3.8	1,713	7.2	5,047	21.2	6,750	28.4
Tonle Sap Freshwater Swamp Forests	25,735	4.1	3,947	15.3	11,579	45.0	25,735	100.0
Tonle Sap-Mekong Peat Swamp Forests	21,604	3.5	1,300	6.0	9,588	44.4	21,597	100.0

Figure 3.19: Area and percent of each ecoregion shifting to a different bioclimatic zone under baseline conditions and as projected for 2030 and 2060 across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by (a) the wetter scenario model; (b) the drier scenario model; and (c) the increased seasonality model (MRC, 2017a; Zomer, 2016).

The extremely hot and mesic zone decreases across seven of 14 ecoregions by 2030 but then has increased substantially across eight ecoregions by 2060 under the highest emissions scenario (RCP 8.5) and the wetter overall model (Figure 3.20). Under the wetter overall scenario the largest increases occur in the Cardamom Mountains Rain Forests, the Central Indochina Dry Forests, the Northern Khorat Plateau Moist Deciduous Forests, the Southeastern Indochina Dry Forests, the Tonle Sap Freshwater Swamp Forests and the Tonle Sap-Mekong Peat Swamp Forests. The proportion of area covered by this bioclimatic zone by 2060 is most significant for the Central Indochina Dry Forests and the Southeastern Indochina Dry Forests given the large area of the basin that is covered by these ecoregions, 253,147 km^2 and 82,504 km^2 respectively.

A similar effect is seen in the drier overall scenario and increased seasonality scenarios (Figures 3.21 and 3.22) although notably the Indochina Mangroves ecoregion is also added to that list of ecoregions experiencing extremely hot and mesic conditions over a substantial portion of their area by 2060. For both of these models it reaches 100 per cent of the Indochina Mangroves ecoregion under the highest emissions scenario even though these extremely hot and mesic conditions are not experienced over any of the current area of the ecoregion, nor under any other future scenarios. Under the increased seasonality scenario, the Northern Annamites Rain Forests and the Northern Khorat Plateau Moist Deciduous Forests also reach close to 100 per cent of their area under extremely hot and mesic conditions by 2060 (Figure 3.22) including under the moderate emissions scenario (RCP 4.5).

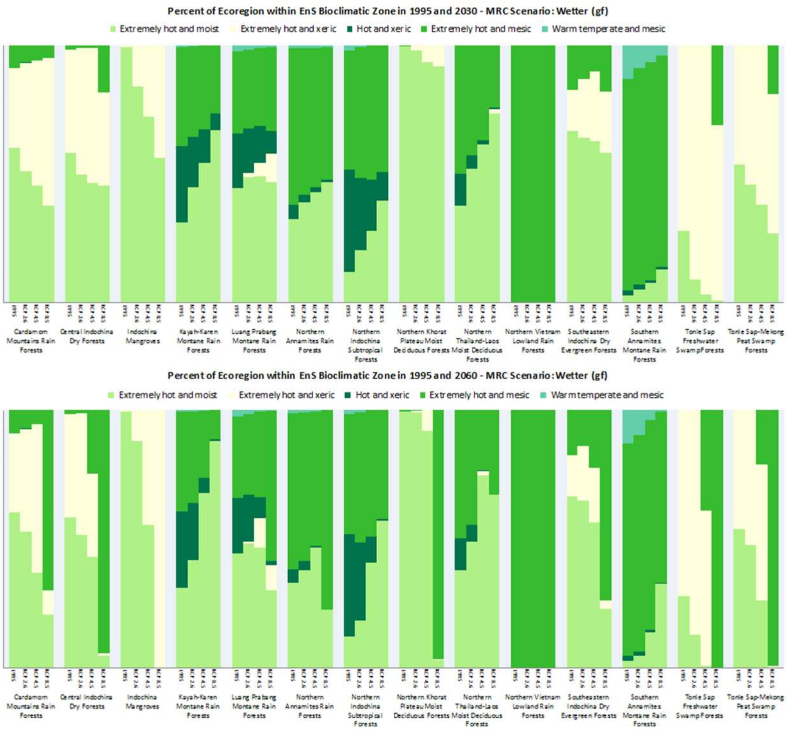


Figure 3.20: Proportion of each ecoregion that experiences each of the five bioclimatic conditions as projected across the three emissions scenarios to 2030 and 2060 under the wetter overall model (MRC, 2017a; Zomer, 2016).

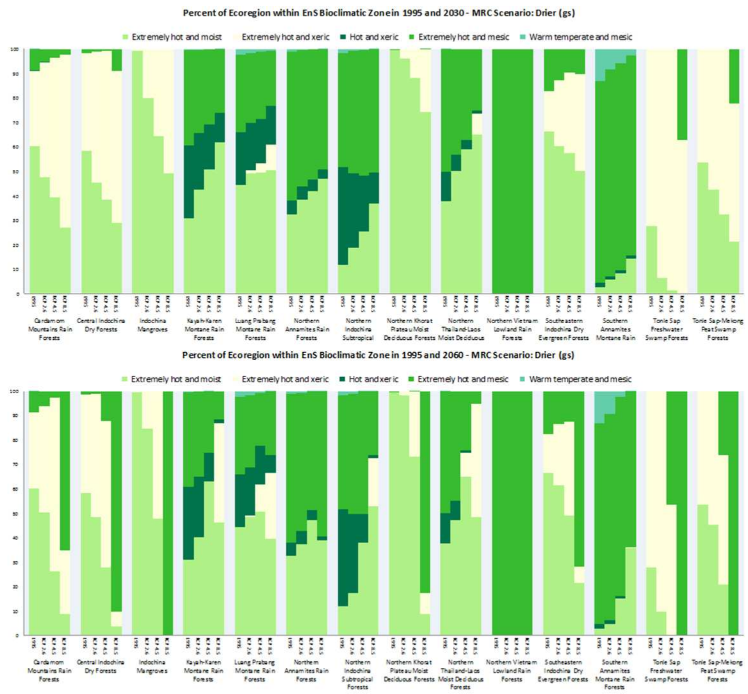


Figure 3.21: Proportion of each ecoregion that experiences each of the five bioclimatic conditions as projected across the three emissions scenarios to 2030 and 2060 under the drier overall model (MRC, 2017a; Zomer, 2016).

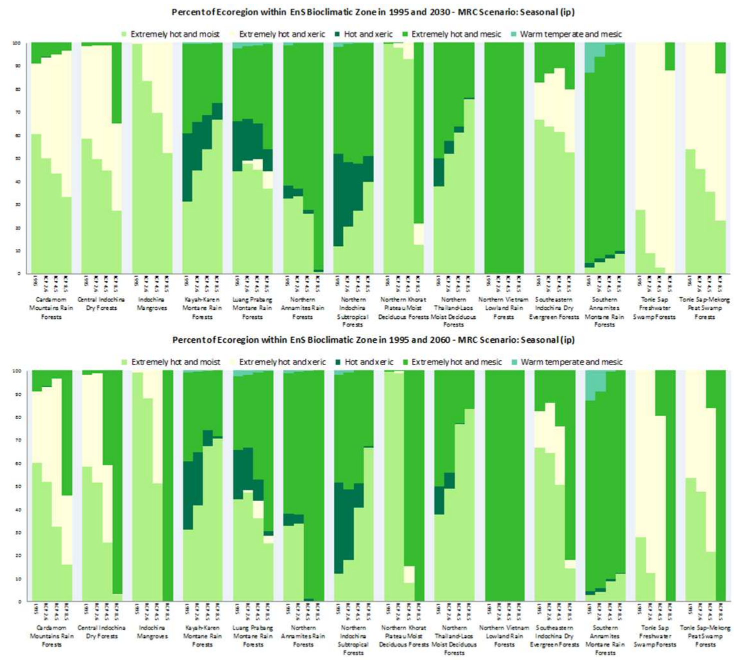


Figure 3.22: Proportion of each ecoregion that experiences each of the five bioclimatic conditions as projected across the three emissions scenarios to 2030 and 2060 under the increased seasonality model (MRC, 2017a).

Under both the wetter and drier overall scenarios (Figures 3.20 and 3.21) areas with warm temperate and mesic conditions, primarily within the Southern Annamites Montane Rain Forests, but also including small areas within Luang Prabang Montane Rain Forests, Northern Annamites, and Northern Indochina Subtropical Forests decrease in proportion markedly, and disappear by 2060 under RCP 8.5. Likewise, there are decreases in the proportion of area experiencing hot and xeric conditions within the Kayah-Karen, Luang Prabang, and Northern Annamites Montane Forests, as well as the Northern Indochina

Subtropical Forests. New areas of extremely hot and xeric and extremely hot and moist in particular start to appear within ecoregions where there were not present before, representing substantial shifts to novel bioclimatic conditions.

Under the increased seasonality scenario (Figure 3.22) the already minimal areas with warm temperate and mesic conditions, primarily within the Southern Annamites Montane Rain Forests, decrease and disappear by 2060 under RCP 8.5. Likewise, there are decreases in the proportion of area experiencing hot and moist conditions within Central Indochina Dry Forest, especially under RCP 8.5 by 2060. New areas with hot and xeric conditions in particular start to appear within ecoregions where they were not present before, representing substantial shifts to novel bioclimatic conditions. Notable examples include changing conditions within the Indochina Mangroves from a homogenous extremely hot and moist zone to substantial portions of extremely hot and xeric, and eventually becoming almost completely hot and xeric by 2060 under RCP 8.5. Both the Tonle Sap Swamp Forest ecoregions give similar examples.

Shift in bioclimatic conditions within existing Protected Areas

More than half of all protected area in the Lower Mekong Basin (about 57,000 km^2) is currently comprised of bioclimatic strata that fall into the Extremely Hot and Moist Zone. The Extremely Hot and Mesic zone, currently found primarily along the eastern highland portions of the Lower Mekong Basin, is the next largest zone, comprising more than 26 per cent of the total area (MRC, 2017a).

For the wetter overall scenario (Figure 3.23), the small area of Warm Temperate and Mesic conditions which are currently within protected areas diminishes under all scenarios, and disappears from the protected area network under RCP 8.5 by 2060. Likewise, the Hot and Xeric strata also substantially diminish. Under this worst case scenario, only the Extremely Hot and Mesic zone expands, covering over 66 per cent of Lower Mekong Basin.

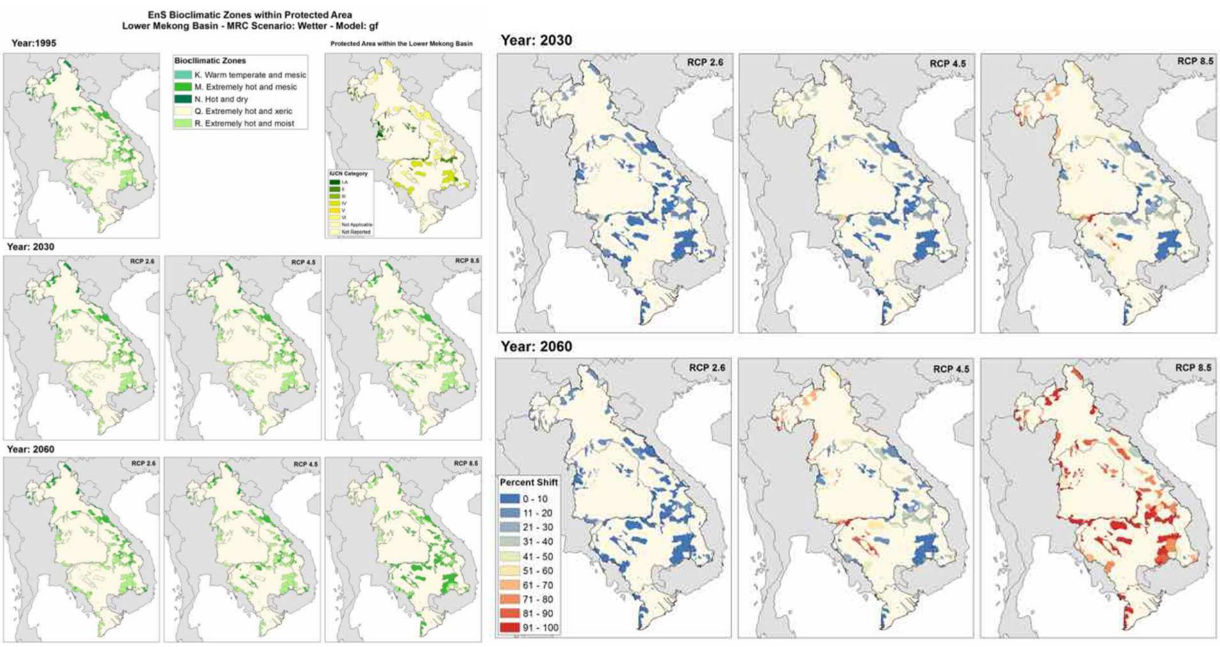


Figure 3.23: (a) Bioclimatic zones within each protected area; and (b) average percent of the area of each Protected Area which shifts to a different bioclimatic zone; under baseline conditions and as projected for 2030 and 2060, across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by the wetter model (MRC, 2017a).

By 2030 the proportion of the protected area estate that has shifted to a different bioclimatic zone ranges between 9.4% and 30.3%. By 2060 the proportion is between 7.3% and 82.2% with the higher emissions scenario leading to more significant shifts in bioclimatic conditions across protected areas.

Under the drier overall scenario (Figure 3.24) the small areas of Warm Temperate and Mesic conditions which are currently within a protected area diminishes under all scenarios, and disappears from the protected area network under RCP 8.5 by 2060. Likewise, the Hot and Xeric zone also substantially diminishes. Under this worst case scenario, only the Extremely Hot and Mesic zone expands, covering up to 58% of Lower Mekong Basin.

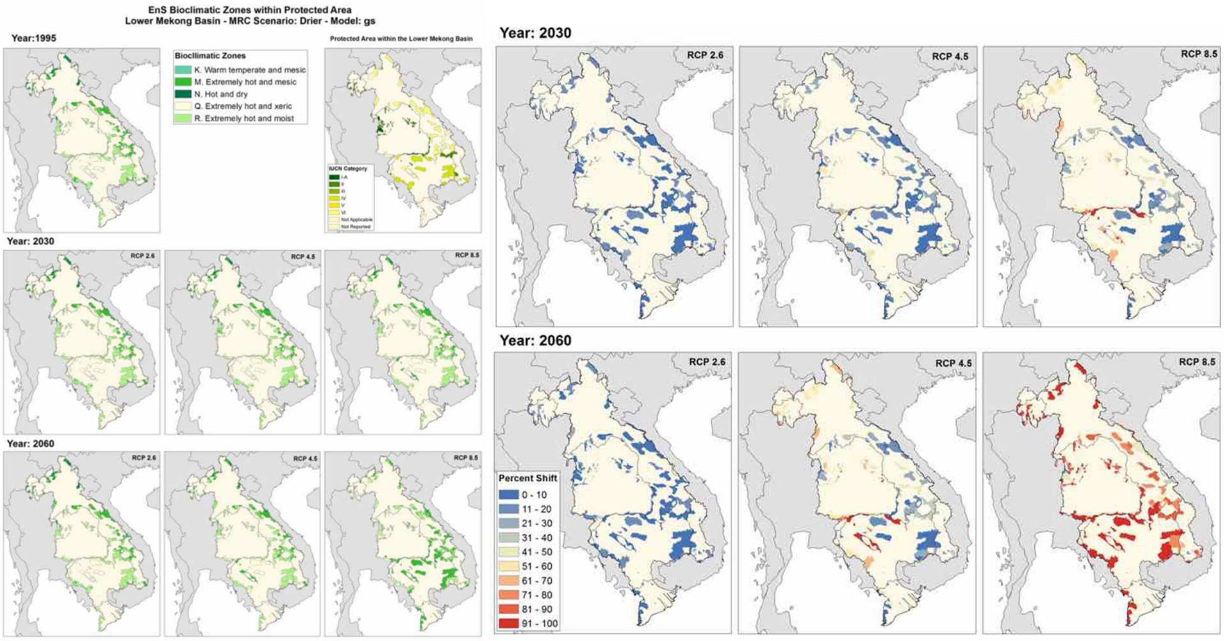


Figure 3.24: (a) Bioclimatic zones within each protected area; and (b) average percent of the area of each Protected Area which shifts to a different bioclimatic zone; under baseline conditions and as projected for 2030 and 2060, across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by the drier model (MRC, 2017a).

By 2030 the proportion of the protected area estate that has shifted to a different bioclimatic zone ranges between 9.4% and 33%. By 2060 the proportion is between 7.3% and 87.1% with the higher emissions scenario leading to more significant shifts in bioclimatic conditions across protected areas.

Under the increased seasonality scenario (Figure 3.25) the small areas of Warm Temperate and Mesic conditions which are currently within protected areas diminishes under all scenarios, and disappears entirely from the protected area network under RCP 8.5 by 2060. Likewise, the Hot and Xeric zone also substantially diminishes. Under this worst case scenario, only the Extremely Hot and Mesic zone expands, covering up to 58 per cent of the Lower Mekong Basin.

By 2030 the proportion of the protected area estate that has shifted to a different bioclimatic zone ranges between 9.4% and 28.9%. By 2060 the proportion is between 7.3% and 75.8% with the higher emissions scenario leading to more significant shifts in bioclimatic conditions across protected areas.

Other studies have also examined the potential impacts on protected areas, habitat and biodiversity as a result of climate change. For instance, USAID (2013) examined the potential climate change threats and vulnerability of natural systems including protected areas, and several species of Non-Timber Forest

Products (NTFPs) and Crop Wild Relatives (CWRs). They found that all protected areas examined had moderate to very high vulnerability to climate change and most NTFPs and CWRs were moderately vulnerable, with some exceptions in the dry broadleaf forests which had a number of species that had high and very high vulnerability to climate change. Of all the variables, an increase in temperature was considered to be the most important due to its impact on flowering, fruiting and seed dispersal.

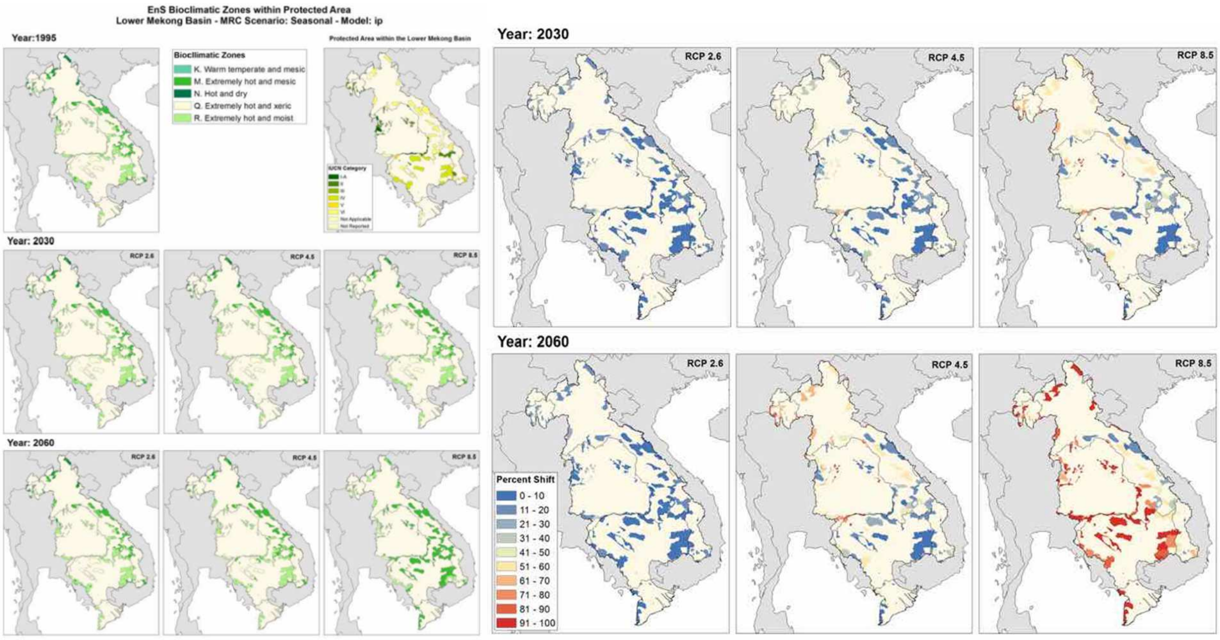


Figure 3.25: (a) Bioclimatic zones within each protected area; and (b) average percent of the area of each Protected Area which shifts to a different bioclimatic zone; under baseline conditions and as projected for 2030 and 2060, across the three emissions scenarios (RCP 2.6; 4.5; 8.5) by the seasonal model (MRC, 2017a).

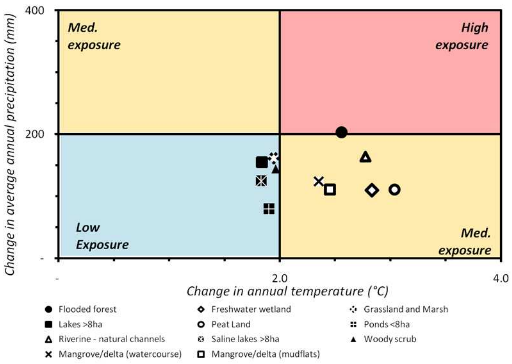
Projected climate change impacts on wetlands

Wetlands are particularly vulnerable to climate change due to their ecological character being fundamentally tied to the hydrological regime; and coastal wetlands, particularly mangroves are expected to be severely impacted by climate change as a result of rising sea-levels, salinity intrusion, and increased temperatures and flooding.

The potential impacts of future climate change on wetlands of the LMB have recently been studied and modelled. In MRC (2015d) four direct climate risks to wetland environments were identified through expert analysis and consultations. These were changes in precipitation, changes in temperature, modified hydrological regime and sea-level rise. The study evaluated the vulnerabilities of habitats at six case study LMB wetlands as a result of these risks. When these were scaled-up to a basin-scale, some habitat vulnerabilities resulting from these risks were identified (Figure 3.26) and included:

- Flooded forests are the most exposed wetland type to climate change, experiencing the largest increases in precipitation with large temperature increases in Cambodia and Lao PDR;
- Riverine, freshwater, mangrove and peat wetlands are all moderately exposed to climate change and are more exposed to temperature increases than to precipitation increases. Changes in temperature are most important for peat lands, freshwater and riverine wetlands, while changes in precipitation are most important for riverine wetlands and mudflats;
- Grasslands, scrub and lakes/ponds are the least exposed to climate change;

- The vast majority of ponds and deltaic/estuarine wetlands together with 70 per cent of flooded forest; 31 per cent of grasslands and marshes, 20 per cent of rivers and streams are highly vulnerable;
- The vast majority of peat lands, lakes (saline and fresh) and un-vegetated mudflats, together with 30 per cent of flooded forests, 60 per cent of rivers and streams and 40-45 per cent of grasslands, swamps, marshes and wood scrub would be moderately vulnerable;
- All estuarine watercourses, together with 45 per cent of swamps and wood scrub, 30 per cent of grasslands and marshes, 20 per cent of rivers and streams and a small fraction of lakes would experience low vulnerability; and
- 34 of 97 important wetland sites across the LMB are considered to be highly vulnerable to climate change, two-thirds of which are in Thailand and Cambodia.



	Vulnerability Areas (Ha)						
Wetland type	High	%	Med	%	Low	%	Total
Wet "lands"							
Flooded forest	2,496	33.0	2,840	37.6	2,217	29.4	7,553
Swamp / woody scrub	304,720	7.6	1,849,538	46.4	1,829,279	45.9	3,983,537
Grasslands and marsh	148,948	30.6	190,210	39.1	147,878	30.4	487,036
Peat lands	2,909	1.3	225,248	98.7			228,157
Open water							
Lakes	1,237	0.4	299,294	92.6	22,704	7.0	323,235
Ponds	121	7.9	1,413	92.1			1,534
Saline lakes					6,686	100.0	6,686
Flowing water							
Riverine	78,215	20.0	229,147	58.6	83,501	21.4	390,863
Coastal, Estuarine and Marine							
Estuarine watercourses					55,546	100.0	55,546
Intertidal lagoon			323	100.0			323
Unvegetated mudflats, beaches					2,876	100.0	2,876
Saltmarsh	1,055	13.3	6,873	86.7			7,928
Mangrove	75,299	100.0					75,299

Figure 3.26: (a) Summary of exposure to climate change (change in temperature and precipitation) of different wetland types; and (b) summary of vulnerability of different wetland types across the LMB based on up-scaling of case study wetland assessments (MRC, 2015d).

MRC (2015d) examined a range of potential sea-level rises by the year 2100 with estimates that by 2100 the seas could be as much as 1.0m higher than at present (IPCC, 2007; MONRE Viet Nam, 2012). A number of recent studies suggest these predictions are conservative and that seal-level rise could reach 1.4 – 2.0 m by the end of the century (Grinsted *et al.,* 2009).

Mapping permanent inundation under these conditions shows that much of the Ca Mau peninsula would be underwater with a sea level rise of 59 cm (Figure 3.27). With a sea level rise of 175 cm the northern region of Ca Mau would be completely inundated (MRC, 2015d). MRC (2015d) also examined the wetland habitats that would be impacted under these conditions. With a 100 cm sea-level rise 33 per cent of estuarine and marine (non-vegetated, bare) sand areas would be covered, as would 99 per cent of grassland and marsh, 72 per cent of mangrove, 80 per cent of natural riverine channels, 100 per cent of salt marsh and 64 per cent of estuarine water courses (Table 3.8)

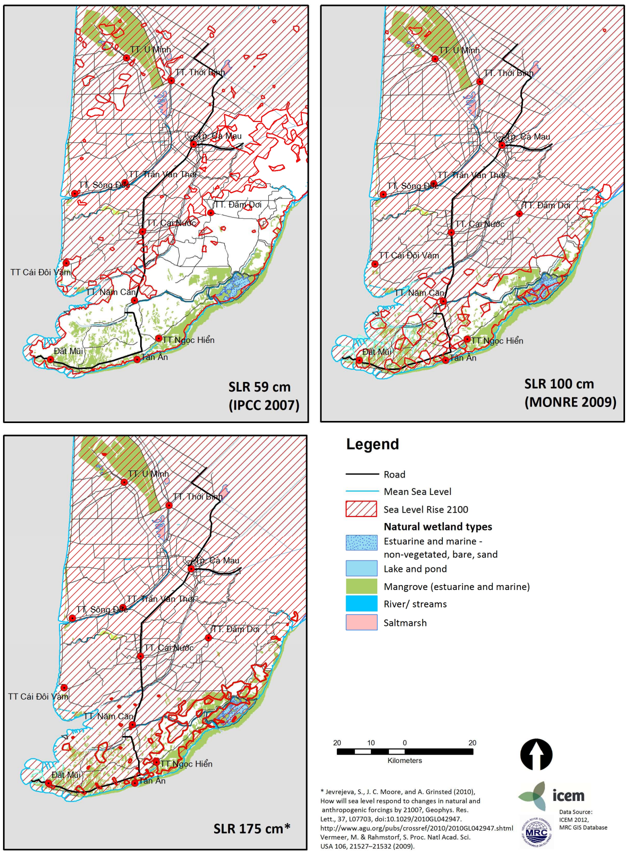


Figure 3.27: Permanent inundation of the Ca Mau peninsula due to climate change with sea level rise of 59 cm, 100 cm and 175 cm (MRC, 2015d).

Table 3.8: Estimates of areas of wetland type in wider Ca Mau covered with sea level rise (MRC, 2015d).

Inundation SLR	Ca Mau total		Estuarine and marine - non-vegetated, bare, sand			Grassland and Marsh			Mangrove		
cm	Ha	% CM	Ha	% CM	% LMB	Ha	% CM	% LMB	Ha	% CM	% LMB
0	37,148	7	4	0	0	0	0	0	11,112	17	1
59	346,920	65	77	3	0	650	99	0	33,437	52	3
100	478,336	89	815	33	0	654	99	0	46,620	72	5
175	511,306	95	2,171	87	1	659	100	0	55,798	86	6
300	537,605	100	2,494	100	1	659	100	0	64,865	100	7
Inundation SLR	Ca Mau total		Riverine - natural channels			Saltmarsh			Estuarine Watercourse		
cm	Ha	% CM	Ha	% CM	% LMB	Ha	% CM	% LMB	Ha	% CM	% LMB
0	37,148	7	15	6	0	139	6	1	513	11	1
59	346,920	65	90	37	0	2,127	99	23	2,142	48	2
100	478,336	89	192	80	0	2,158	100	23	2,874	64	3
175	511,306	95	209	86	0	2,158	100	23	3,587	80	4
300	537,605	100	242	100	0	2,158	100	23	4,460	100	5

Projected climate change impacts on species

The species vulnerability assessments undertaken for the MRC's basin-wide impact assessment on biodiversity and ecosystems followed the protocol originally developed for IUCN by Foden *et al*. (2013) and later applied to the same groups as in this study by Carr *et al*. (2013). This approach uses a biological trait-based approach, which combines elements of species' sensitivity (the inability to tolerate change), low adaptive capacity (the inability to adapt to change through dispersal to new areas or through genetic micro-evolution), and exposure (the changes to which a given species is expected to be exposed throughout its current range) to determine the vulnerability of a species to climate change (Figure 3.28). Species that are most highly Exposed, Sensitive and Unadaptable are considered most vulnerable to climate change. The approach considers that predicted changes in climatic variables such as phenology, temperature, rainfall, extreme events and carbon dioxide concentrations will impact on species in a range of different ways (Figure 3.29).

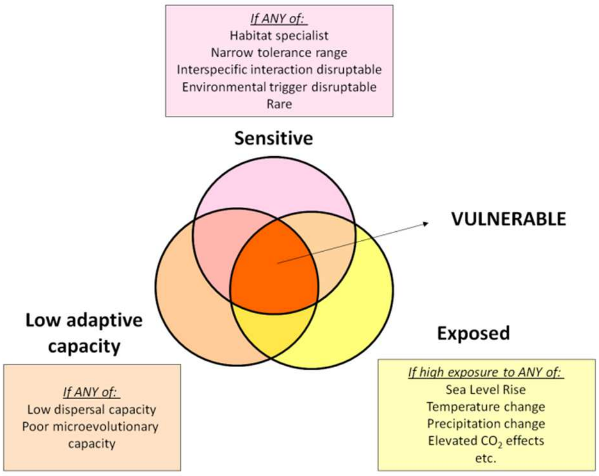


Figure 3.28: The three dimensions of species vulnerability: (i) Sensitivity; (ii) Adaptive Capacity; (iii) Exposure; and the biological and ecological trait groups and logic system used to classify species as high vulnerability in each dimension (from Carr *et al.* 2013).

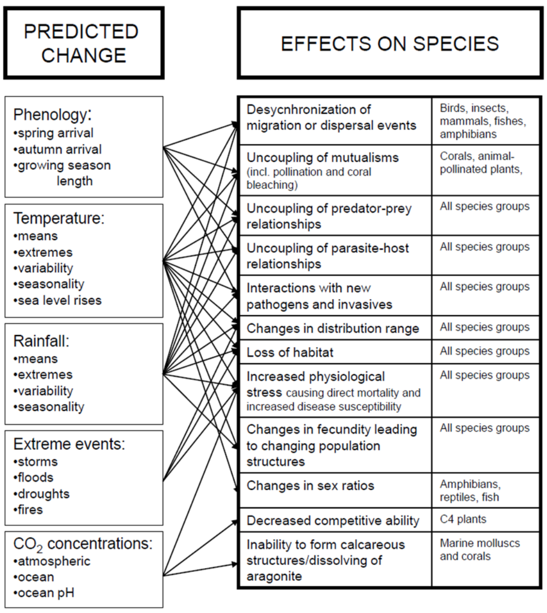


Figure 3.29: Summary of some of the predicted impacts of climate change on species (from Foden *et al.* 2008).

Using expert workshops and other consultations, Foden *et al*. (2008) identified more than 90 biological and ecological traits associated with sensitivity and low adaptability to climate change. Traits that are believed to render a species sensitive to climate change were divided into five categories and traits that render a species poorly able to adapt to change were divided into two categories (MRC, 2017b).

Under each of these trait categories a number of traits were identified that are applicable to the species group under consideration within the LMB. Sensitivity, Low Adaptability and Exposure scores for each species were assembled and overall vulnerability scores calculated according to two simple logic steps: species were assigned a high score under each vulnerability dimension if they have any contributing trait (e.g. considered sensitive due to being a habitat specialist). They were considered highly vulnerable overall, however, only if they scored as 'high' for all three dimensions of exposure, sensitivity and adaptive capacity. To account for missing trait data, each of the previous steps was run twice; missing trait information was firstly assumed to represent a low vulnerability score and secondly to represent high scores. This provided best-case (or optimistic) and worst-case (pessimistic) scenarios, respectively. Using expert analysis and modelled exposure of each species to climate change (MRC, 2017b) the numbers of vulnerable species are provided in tables 3.9 to 3.14.

Table 3.9: Total numbers of climate change vulnerable amphibians (91 assessed) for all exposure modelling parameter combinations projected to 2030 and 2060, for RCPs 4.5 and 8.5 using optimistic and pessimistic assumptions about missing data points for all three GCMs (MRC, 2017b).

	2030						2060					
	RCP2.6		RCP4.5		RCP8.5		RCP2.6		RCP4.5		RCP8.5	
	Opt	***Pes***	***Opt***	***Pes***	***Opt***	***Pes***	***Opt***	***Pes***	***Opt***	***Pes***	***Opt***	***Pes***
Increased seasonality	0	0	0	1	11	25	0	0	13	31	35	69
Wetter overall	0	0	1	1	17	30	0	0	19	35	35	69
Drier overall	0	0	6	10	18	33	0	0	21	37	35	69

Under the baseline parameters of RCP4.5 and the year 2060, between 13 and 37 of the LMB amphibian species assessed are considered to be vulnerable to climate change, depending on the specific model considered and the assumptions made for missing data points. Table 3.9 shows that when considering all models, concentration pathways, time periods and assumptions of missing data values (but using thresholds from our baseline parameters) total numbers of climate change vulnerable species range from zero (under all combinations of RCP2.6 and the IP model and RCP4.5, by 2030, and an optimistic assumption of missing data values) to 69 (76%) (all three models and RCP8.5, by 2060, and a pessimistic assumption of missing data values).

Table 3.10: Total numbers of climate change vulnerable birds (100 assessed) for all exposure modelling parameter combinations projected to 2030 and 2060, for RCPs 4.5 and 8.5 using optimistic and pessimistic assumptions about missing data points for all three GCMs (MRC, 2017b).

	2030						2060					
	RCP2.6		RCP4.5		RCP8.5		RCP2.6		RCP4.5		RCP8.5	
	Opt	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*
Increased seasonality	0	0	4	4	53	69	0	0	33	43	57	75
Wetter overall	0	0	0	0	56	73	0	0	35	45	57	75
Drier overall	0	1	9	12	55	73	0	0	28	40	57	75

Under the baseline parameters of RCP4.5 and the year 2060, between 28 and 45 of the LMB bird species assessed are considered to be vulnerable to climate change, depending on the specific model considered and the assumptions made for missing data points. Table 3.10 shows that when considering all models, concentration pathways, time periods and assumptions of missing data values (but using thresholds from our baseline parameters) total numbers of climate change vulnerable species range from zero (under most combinations of RCP2.6 and the GF model and RCP4.5, by 2030) to 75 (75%) (all three models and RCP8.5, by 2060, and a pessimistic assumption of missing data values).

Table 3.11: Total numbers of climate change vulnerable fish (155 assessed) for all exposure modelling parameter combinations projected to 2030 and 2060, for RCPs 4.5 and 8.5 using optimistic and pessimistic assumptions about missing data points for all three GCMs (MRC, 2017b).

	2030						2060					
	RCP2.6		RCP4.5		RCP8.5		RCP2.6		RCP4.5		RCP8.5	
	Opt	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*
Increased seasonality	0	0	7	7	31	33	0	0	49	51	124	131
Wetter overall	0	0	3	3	45	46	0	0	57	58	124	131
Drier overall	0	0	4	4	39	40	0	0	45	47	124	131

Under the baseline parameters of RCP4.5 and the year 2060, between 45 and 58 of the LMB freshwater fish species assessed are considered to be vulnerable to climate change, depending on the specific model considered and the assumptions made for missing data points. Table 3.11 shows that when considering all models, concentration pathways, time periods and assumptions of missing data values (but using thresholds from our baseline parameters) total numbers of climate change vulnerable species range from zero (under all combinations of RCP2.6) to 131 (84.5%) (all three models and RCP8.5, by 2060, and a pessimistic assumption of missing data values).

Table 3.12: Total numbers of climate change vulnerable mammals (108 assessed) for all exposure modelling parameter combinations projected to 2030 and 2060, for RCPs 4.5 and 8.5 using optimistic and pessimistic assumptions about missing data points for all three GCM (MRC, 2017b).

	2030						2060					
	RCP2.6		RCP4.5		RCP8.5		RCP2.6		RCP4.5		RCP8.5	
	Opt	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*
Increased seasonality	1	4	4	7	44	78	5	8	36	47	58	108
Wetter overall	2	5	6	13	33	49	1	4	42	61	58	108
Drier overall	0	0	10	13	28	37	1	3	37	56	58	108

Under the baseline parameters of RCP4.5 and the year 2060, between 36 and 51 of the LMB mammal species assessed are considered to be vulnerable to climate change, depending on the specific model considered and the assumptions made for missing data points. Table 3.12 shows that when considering all models, concentration pathways, time periods and assumptions of missing data values (but using thresholds from our baseline parameters) total numbers of climate change vulnerable species range from zero (under the IP model and RCP2.6, by the year 2030) to 108 (100%) (all three models and RCP8.5, by 2060, and a pessimistic assumption of missing data values).

Table 3.13: Total numbers of climate change vulnerable reptiles (69 assessed) for all exposure modelling parameter combinations projected to 2030 and 2060, for RCPs 4.5 and 8.5 using optimistic and pessimistic assumptions about missing data points for all three GCMs (MRC, 2017b).

	2030						2060					
	RCP2.6		RCP4.5		RCP8.5		RCP2.6		RCP4.5		RCP8.5	
	Opt	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*
Increased seasonality	0	0	3	7	9	17	0	0	11	22	17	48
Wetter overall	0	0	0	1	8	19	0	0	13	36	17	48
Drier overall	0	0	2	6	10	19	0	0	12	23	17	48

Under the baseline parameters of RCP4.5 and the year 2060, between 11 and 36 of the LMB plant species assessed are considered to be vulnerable to climate change, depending on the specific model considered and the assumptions made for missing data points. Table 3.13 shows that when considering all models, concentration pathways, time periods and assumptions of missing data values (but using thresholds from our baseline parameters) total numbers of climate change vulnerable species range from zero (under all combinations of RCP2.6 by 2030 and 2060, and using model GF and RCP4.5 by 2030) to 48 (81%) (all three models and RCP8.5, by 2060, and a pessimistic assumption of missing data values).

Table 3.14: Total numbers of climate change vulnerable plants (83 assessed) for all exposure modelling parameter combinations projected to 2030 and 2060, for RCPs 4.5 and 8.5 using optimistic and pessimistic assumptions about missing data points for all three GCMs (MRC, 2017b).

	2030						2060					
	RCP2.6		RCP4.5		RCP8.5		RCP2.6		RCP4.5		RCP8.5	
	Opt	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*	*Opt*	*Pes*
Increased seasonality	0	0	2	3	29	33	0	0	29	41	60	83
Wetter overall	0	0	2	5	34	41	0	0	34	48	60	83
Drier overall	0	0	5	6	21	31	0	0	21	35	60	83

Under the baseline parameters of RCP4.5 and the year 2060, between 21 and 48 of the LMB plant species assessed are considered to be vulnerable to climate change, depending on the specific model considered and the assumptions made for missing data points. Table 3.14shows that when considering all models, concentration pathways, time periods and assumptions of missing data values (but using thresholds from our baseline parameters) total numbers of climate change vulnerable species range from zero (under all combinations of RCP2.6 by 2030) to 83 (100%) (all three models and RCP8.5, by 2060, and a pessimistic assumption of missing data values).

In summary, the range in overall number of species in each functional group assessed as climate change vulnerable across the three models used and considering both optimistic and pessimistic assumptions under a medium emissions scenario (RCP4.5) to 2060 are provided in Table 3.15. Different functional groups of species will be affected in different ways depending on the biological traits that determine the sensitivity to climate change and the capacity to adapt of individual species.

Sensitivity traits that were relatively common across a large number of species and functional groups were: (i) dependence on a specific flooding regime; (ii) intolerance of drought conditions; (iii) sensitivity to a change in fire regime; (iv) dependent on a climate trigger to initiate some key life-history process or activity; and (v) tolerance to only a narrow range of climate conditions (temperature and/or precipitation) (MRC, 2017b). Across all groups the most common factor relating to low adaptive capacity was the presence of dispersal-restricting barriers (MRC, 2017b).

Table 3.15: Total numbers and percentages of species assessed as climate change vulnerable, for each species group, using baseline parameters for RCP4.5 to 2060. Lower and upper values show variation between all models used and assumptions of missing data points (MRC, 2017b).

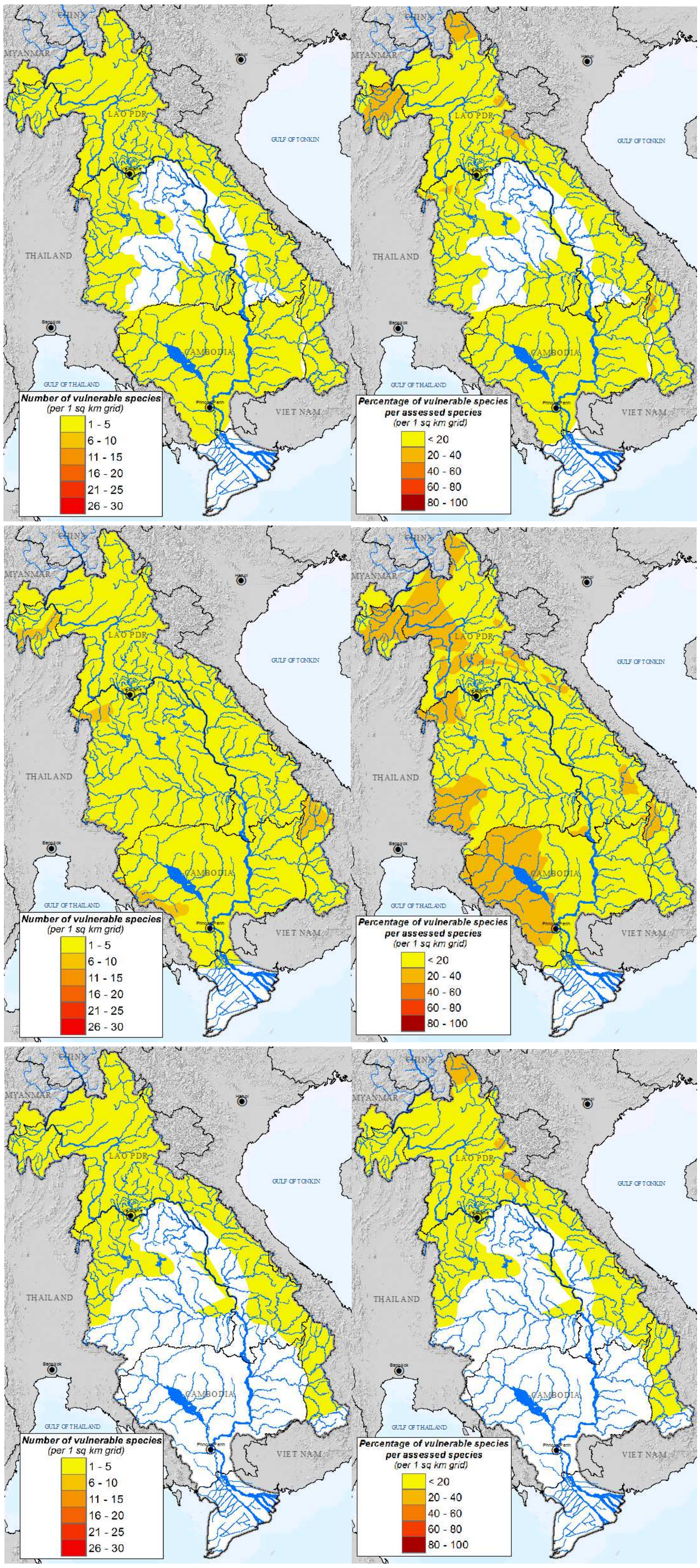
Species Group	Total species assessed	Number (and percentage) of species assessed as sensitive	Number (and percentage) of species assessed as poorly able to adapt	Lower number (and percentage) of species assessed as climate change vulnerable	Upper number (and percentage) of species assessed as climate change vulnerable
Amphibians	91	72 (79%)	47 (52%)	13 (14%)	37 (41%)
Birds	100	92 (92%)	61 (61%)	28 (28%)	45 (45%)
Freshwater fish	155	154 (>99%)	125 (81%)	45 (29%)	58 (37%)
Mammals	108	60 (56%)	104 (96%)	36 (33%)	51 (57%)
Plants	83	80 (96%)	76 (92%)	21 (25%)	48 (58%)
Reptiles	59	46 (78%)	18 (30%)	11 (19%)	36 (61%)

Species vulnerability hotspots

Regional variations in climate change mean that the impacts on species and functional groups are likely to be different in different areas. Hotspots of vulnerability for all functional groups depend significantly on the model selected (Figures 3.30-3.35). Under the increased seasonality model and a moderate climate scenario (RCP4.5) with optimistic assumptions, areas that stand out as hotspots across multiple species groups include Tonle Sap and surrounding provinces, which was highlighted on several maps as containing notable numbers of climate change vulnerable birds, reptiles and plants, and the main channel of the Mekong River which contains large numbers of climate change vulnerable freshwater fish. Also along the Mekong River, as highlighted on several maps, one can find large numbers of climate change vulnerable plants (from north of Vietnam delta to Lao and Thai (Chiang Rai Province)), reptiles (especially at Mekong Delta – including most of lower part close to sea and areas close to the Cambodian border) and a few mammals (from Kratie province to the Lao PDR border).

In central Lao PDR, maps suggest that one can find large numbers of climate change vulnerable birds (including in parts of Phonsavan, Borkhamxay and Khammoune Provinces) and reptiles (in particular, close to the Thai border). In northern Thailand, including areas close to the Lao border, maps suggest that one can find large numbers of climate change vulnerable amphibians, birds and mammals, and concentrations of vulnerable amphibians extend into northern Lao PDR.

In north-eastern Cambodia, and in particular close to the Viet Nam border, some maps suggest that one may find large numbers of climate change vulnerable amphibians, while in northern Cambodia, an area that extends into Pakse Province, Lao PDR, maps suggest that one may find large numbers of climate change vulnerable birds.

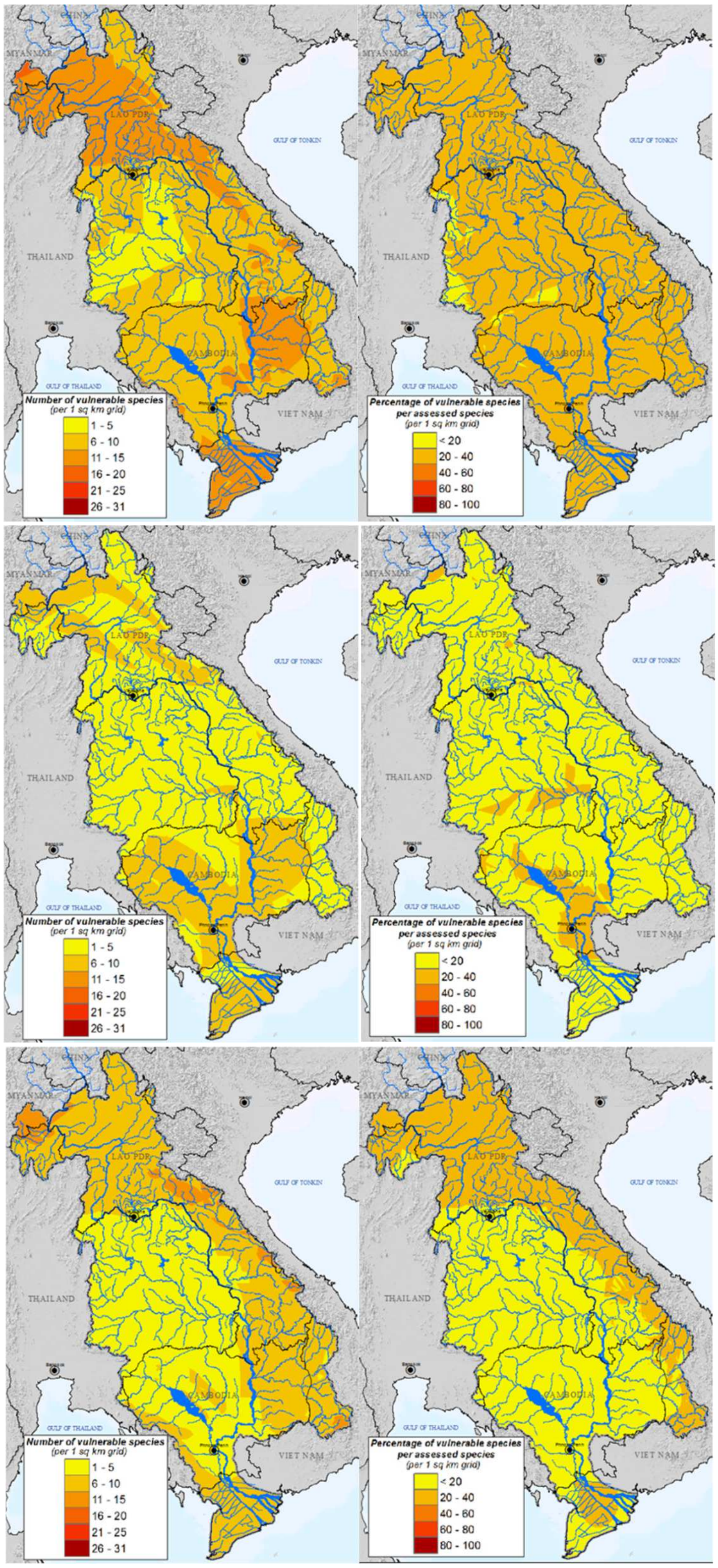


(a)

(b)

(c)

Figure 3.30: Distribution of climate change vulnerable amphibians in the LMB for (a) wetter overall; (b) drier overall; and (c) increased seasonality models for RCP4.5 to 2060 with optimistic assumptions. The map on the left for each model shows the total numbers of climate change vulnerable amphibian species per grid cell and the map on the right for each model shows the percentage of climate change vulnerable amphibians per grid cell (MRC, 2017b).



(a)

(b)

(c)

Figure 3.31: Distribution of climate change vulnerable birds in the LMB for (a) wetter overall; (b) drier overall; and (c) increased seasonality models for RCP4.5 to 2060 with optimistic assumptions. The map on the left for each model shows the total numbers of climate change vulnerable amphibian species per grid cell and the map on the right for each model shows the percentage of climate change vulnerable amphibians per grid cell (MRC, 2017b).

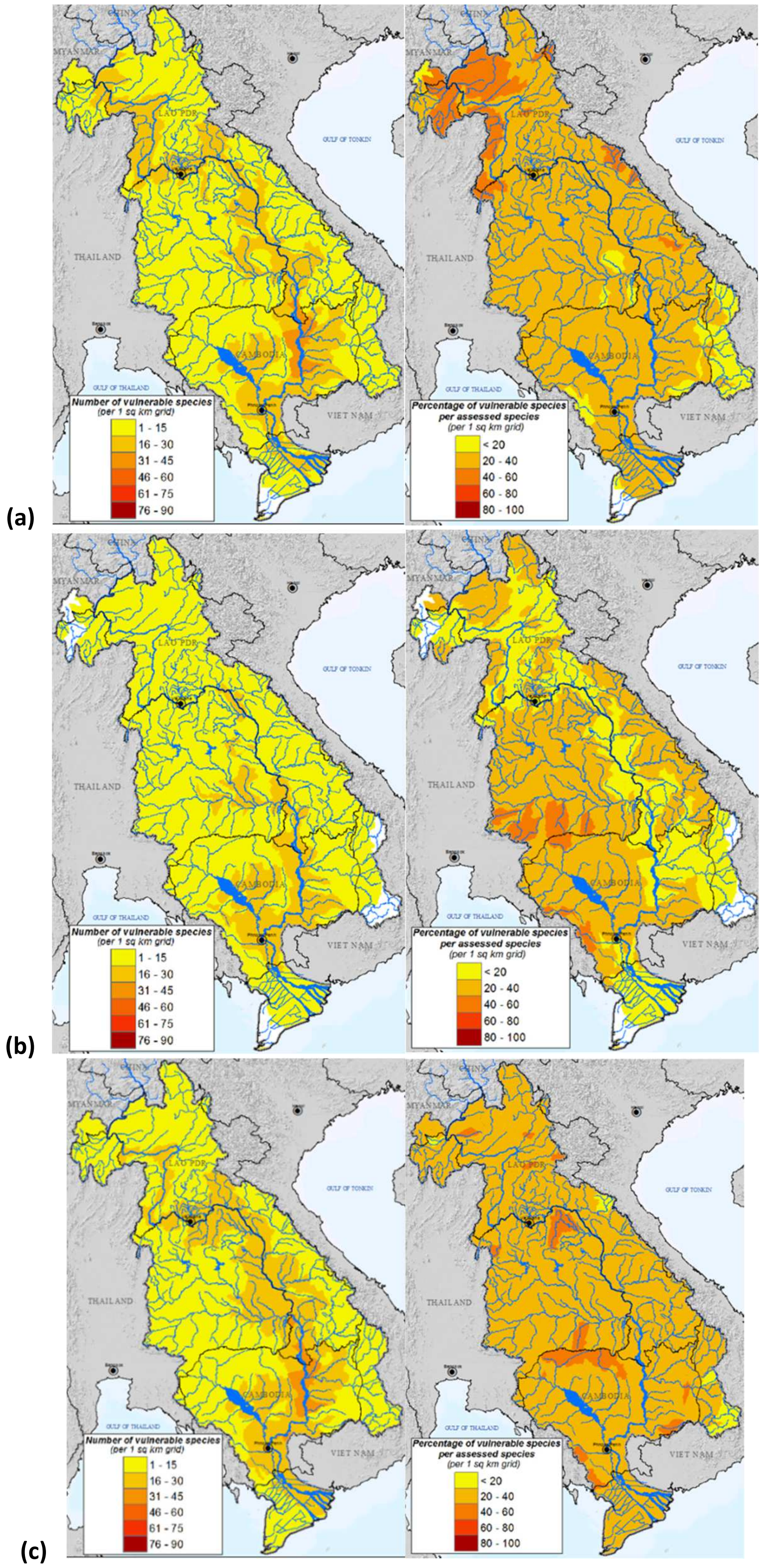


Figure 3.32: Distribution of climate change vulnerable fish in the LMB for (a) wetter overall; (b) drier overall; and (c) increased seasonality models for RCP4.5 to 2060 with optimistic assumptions. The map on the left for each model shows the total numbers of climate change vulnerable amphibian species per grid cell and the map on the right for each model shows the percentage of climate change vulnerable amphibians per grid cell (MRC, 2017b).

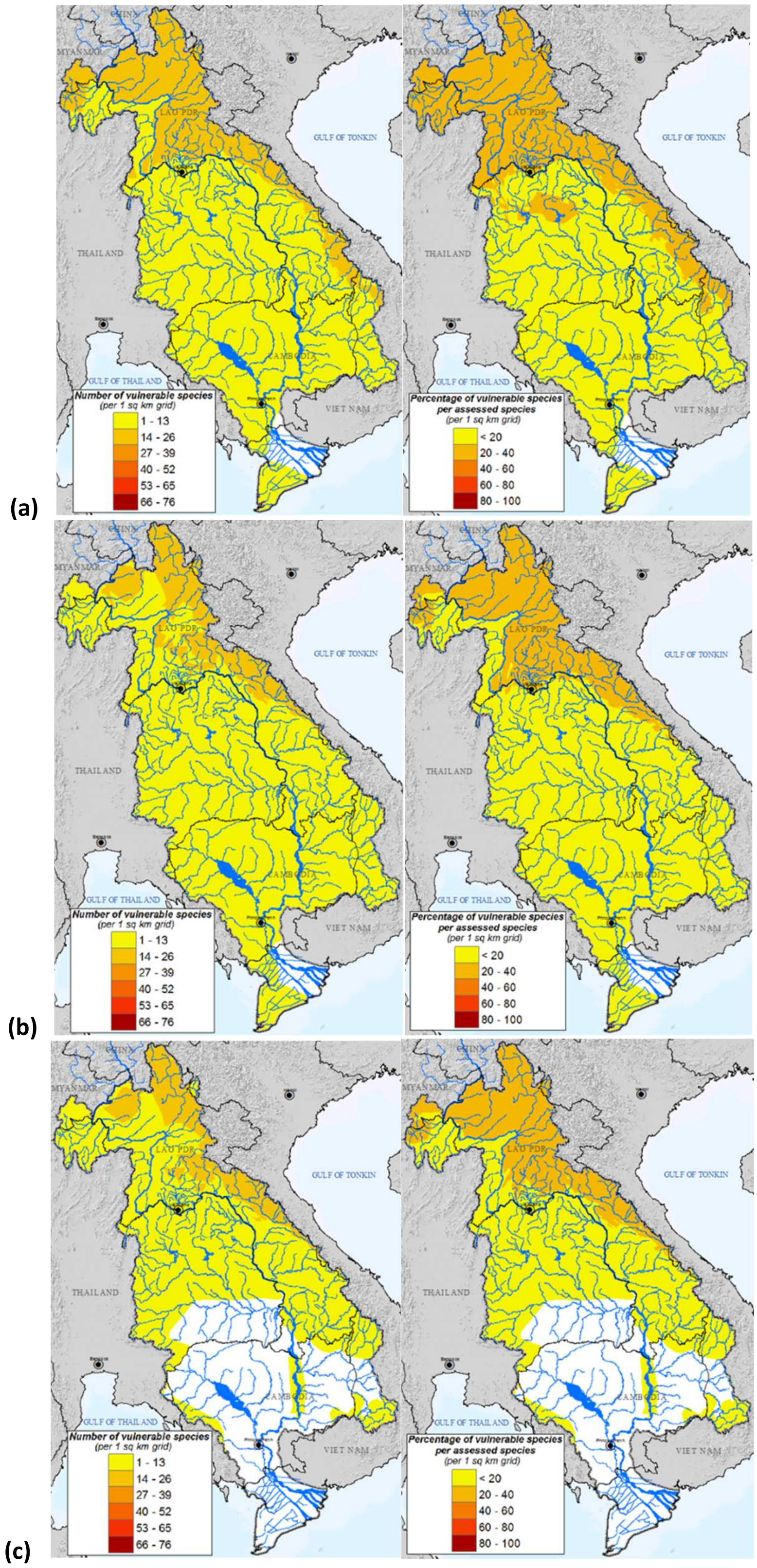
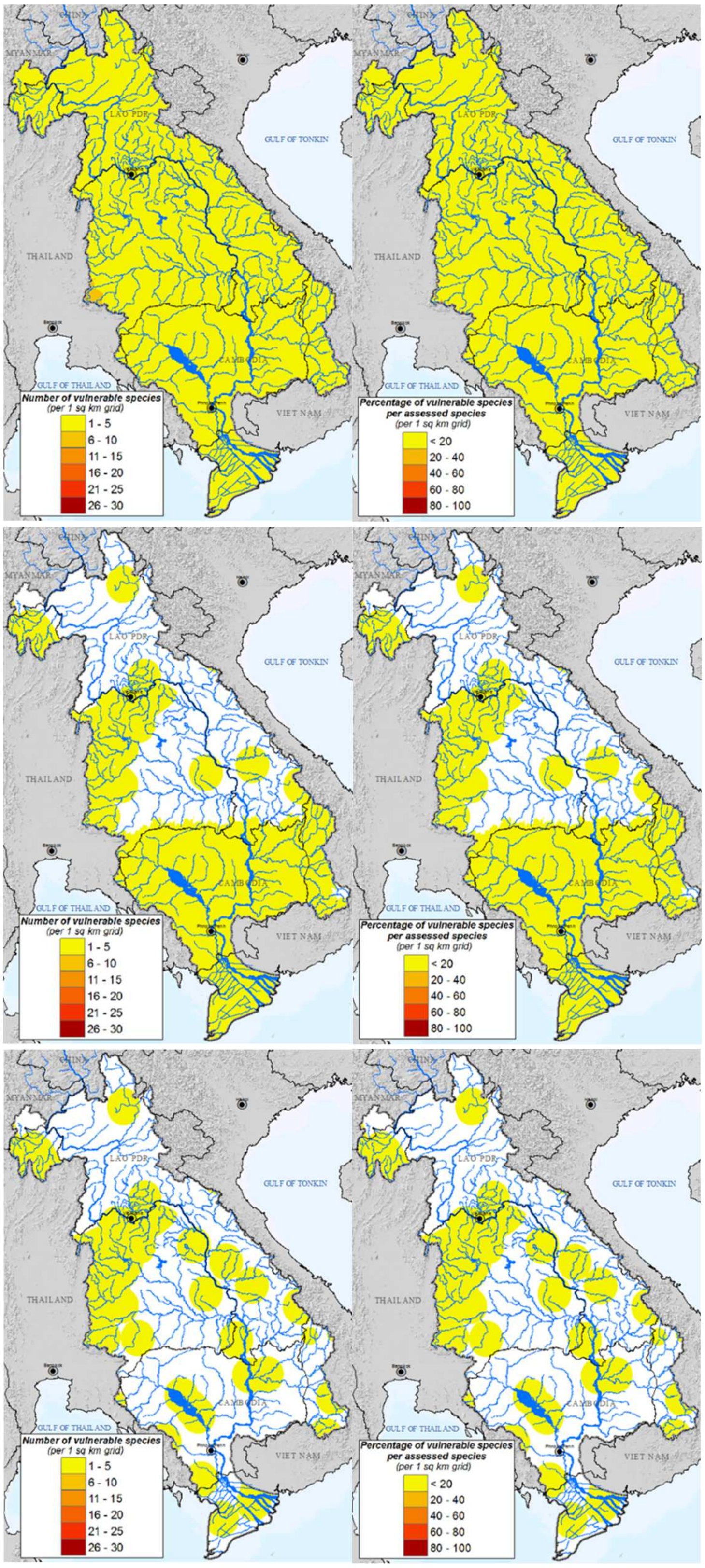


Figure 3.33: Distribution of climate change vulnerable mammals in the LMB for (a) wetter overall; (b) drier overall; and (c) increased seasonality models for RCP4.5 to 2060 with optimistic assumptions. The map on the left for each model shows the total numbers of climate change vulnerable amphibian species per grid cell and the map on the right for each model shows the percentage of climate change vulnerable amphibians per grid cell (MRC, 2017b).



(a)

(b)

(c)

Figure 3.34: Distribution of climate change vulnerable reptiles in the LMB for (a) wetter overall; (b) drier overall; and (c) increased seasonality models for RCP4.5 to 2060 with optimistic assumptions. The map on the left for each model shows the total numbers of climate change vulnerable amphibian species per grid cell and the map on the right for each model shows the percentage of climate change vulnerable amphibians per grid cell (MRC, 2017b).

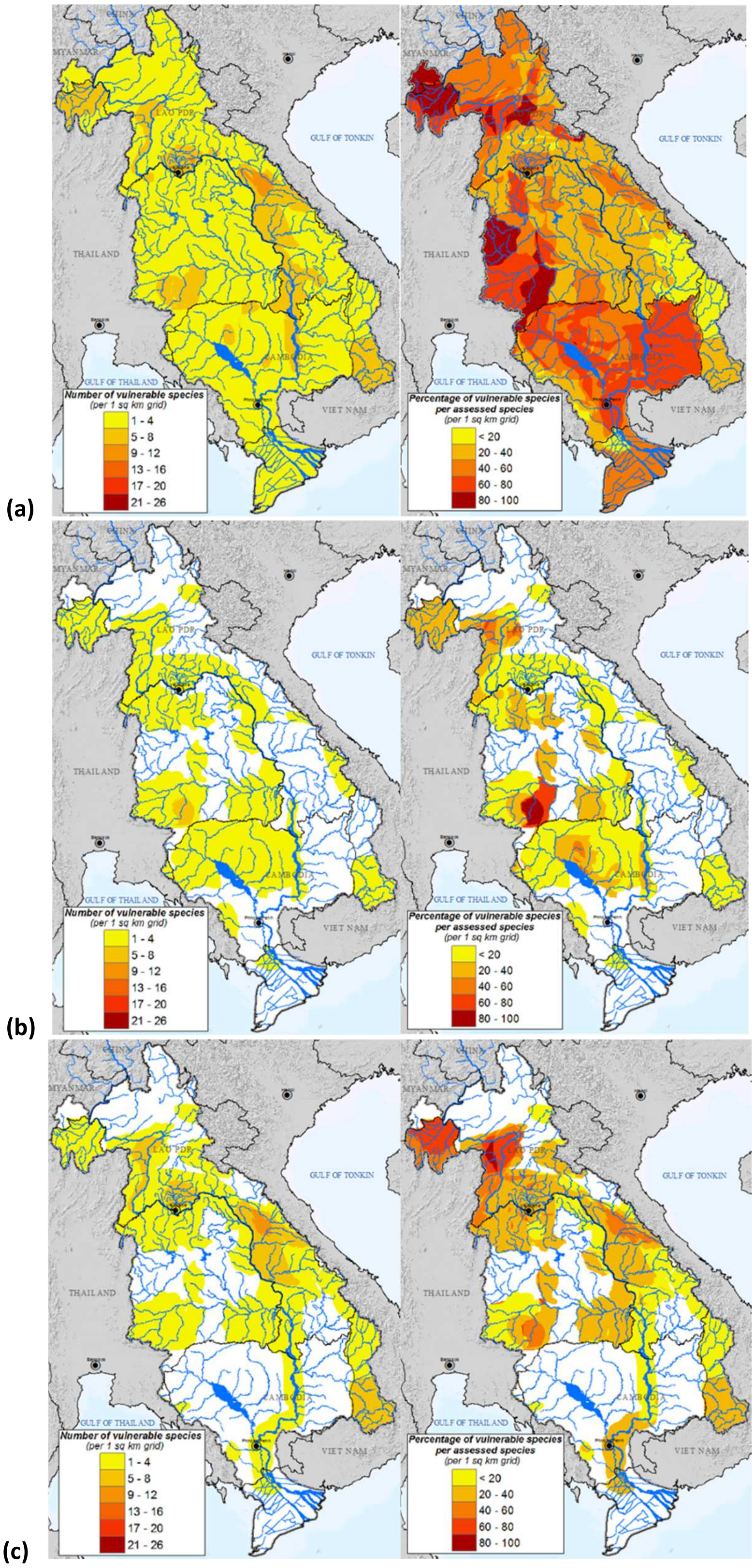


Figure 3.35: Distribution of climate change vulnerable plants in the LMB for (a) wetter overall; (b) drier overall; and (c) increased seasonality models for RCP4.5 to 2060 with optimistic assumptions. The map on the left for each model shows the total numbers of climate change vulnerable amphibian species per grid cell and the map on the right for each model shows the percentage of climate change vulnerable amphibians per grid cell (MRC, 2017b).

Projected climate change impacts on ecosystem services

A comprehensive review of Mekong ecosystem services in the past, current status, possible future was undertaken by WWF (2013). The report indicated that ecosystem services provided in the basin are under pressure from a number of threats, including rapid economic development, population growth, unsustainable resource use, and future climate change. Examples of predicted impacts from climate change are species loss, altered ecosystem composition, shifts in habitat ranges of species, changed hydrological patterns, increased occurrence of extreme events, and poor crop production and crop failure. MRC (2017c) identifies a range of other ecosystem services assessments conducted throughout the LMB in recent years.

MRC (2017c) undertook an assessment of the current distribution and extent of four ecosystem services in the LMB and the potential basin-wide climate change impacts on three of them across the range of scenarios described in Chapter One. The three ecosystem services assessed were water yield, sediment retention, and nutrient retention, while a baseline scenario was also determined for carbon storage. The InVest suite of models was used to assess potential future impacts due to climate change. For details of the methodology and data used see MRC (2017c).

(a) Water Yield

The predicted annual water yields in 2030 and 2060 derived from a *drier overall* model in combination with medium (RCP4.5) and high (RCP8.5) emissions scenarios indicated that a substantial reduction of predicted water yields by 9-24 per cent from the average runoff during 1986-2005. A greater loss is predicted in Lao PDR under the drier overall scenario (-39%) followed by Thailand and Cambodia (-30%).

In contrast, the increased seasonality scenario and the wetter overall scenario (an increase annual rainfall by 10-20 per cent from the current) in conjunction with high emissions, is expected to result in an increase of 5-26 per cent in runoff at the basin-scale. The current water yield in Lao PDR is projected to increase from 251.0 km^3 to 325.4 km^3 by 2060. Similarly, the annual water yield in Thailand is projected to increase 30 per cent above the baseline during this period.

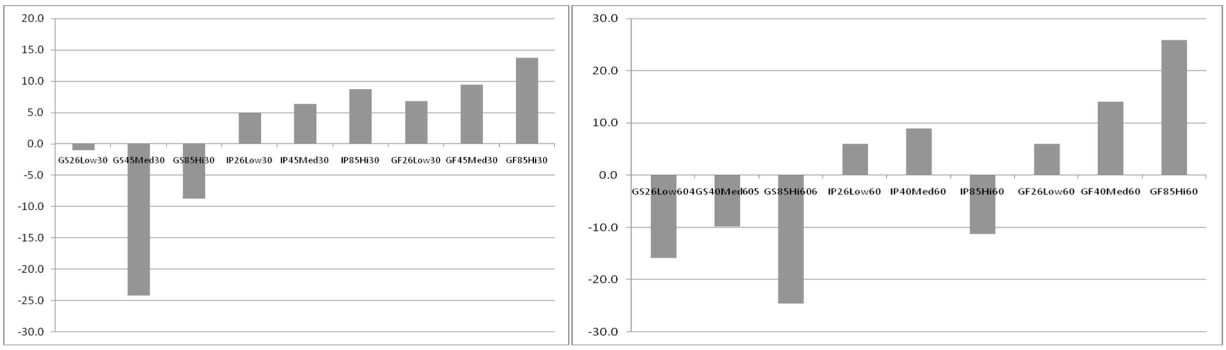


Figure 3.36: Percentage change in annual water yield in (a) 2030 and (b) 2060 for each of the nine future climate scenarios (MRC, 2017c).

Changes in water yield of this scale may have considerable impacts on agricultural production in different parts of the LMB. MRC (2017c) identify several potential strategies to mitigate against this, including increased irrigation supply in some areas, modified planting calendars, and investigating alternative crop varieties and crops. However, further work on potential impacts is recommended.

(b) Sediment retention

To predict soil loss areas of the basin were classified into five classes each defining the severity of soil loss defined in the international standard: very low (≤ 6.25 ton/ha/year), low (6.26-31.25 ton/ha/year), moderate (31.26-125.00 ton/ha/year), severe (125.01-625.00 ton/ha/year) and very severe (> 625.00 ton/ha/year) (LDD Thailand, 2000). The analysis of results presented in MRC (2017c) (Table 3.16) indicates that the area of the basin in different erosion classes is similar among all future climate scenarios. The accumulated areas categorized from moderate to very severe are projected to decrease by 2% from 2010 to 2030.

Table 3.16: Changes in soil erosion and sediment load under different climate change scenarios (MRC, 2017c).

Scenarios	Average soil loss	Change relative to baseline (%)		
	(ton/ha)	Sediment retention	Sediment export	Soil loss
Baseline (million tones)				
Total		7,415	175	2,700
Average	43.2	118.7	2.8	100
2030				
Drier overall 2.6	45.7	-8.8	-16.5	5.7
Drier overall 4.5	38.7	-22.8	-29.4	-10.6
Drier overall 8.5	43.7	-12.9	-20.2	1.0
Increased seasonality 2.6	47.8	-4.6	-12.5	10.6
Increased seasonality 4.5	48.6	-3.1	-10.9	12.5
Increased seasonality 8.5	49.9	-0.5	-8.4	15.5
Wetter overall 2.6	48.0	-4.0	-12.3	10.9
Wetter overall 4.5	48.9	-2.0	-10.5	13.1
Wetter overall 8.5	50.4	1.3	-7.7	16.6
2060				
Drier overall 2.6	45.9	-8.3	-16.0	6.2
Drier overall 4.5	43.6	-13.1	-20.4	0.7
Drier overall 8.5	40.2	-20.1	-26.6	-7.1
Increased seasonality 2.6	47.7	-4.7	-12.8	10.3
Increased seasonality 4.5	50.1	-0.3	-8.1	15.8
Increased seasonality 8.5	53.7	6.6	-1.2	24.2
Wetter overall 2.6	47.7	-4.7	-12.8	10.3
Wetter overall 4.5	50.5	1.6	-7.5	16.9
Wetter overall 8.5	54.7	10.5	0.2	26.4

According to the wetter climate and high emission scenario (an increase of 300 mm rainfall and 3°C with respect to current rainfall), an increase of 2% of moderate to very severe classes is predicted. A reduction of the current annual rainfall by approximately 220-250 mm (drier overall scenario) would decrease the predicted soil loss by approximately 5 tonne per hectare per year. In contrast, an increase in annual rainfall of 300 mm would substantially increase the amount of soil loss. An additional 10 tonne per hectare per year of soil erosion is predicted with respect to current conditions under the wetter climate scenario.

Changes in spatial patterns of soil loss in sub-watersheds are more notable than the changes for the entire LMB. This is due to the variability of different sub-watersheds in terms of remaining forest cover, soil texture and topography. Substantial reduction of soil loss is predicted for Nam Ou sub-watershed in Vietnam and Nam Nuao sub-watershed in Lao PDR under the drier climate and moderate high emission scenarios in. A reduction of 15% and 20-25% with respect to the current soil loss is expected in years 2030 in each sub-basin respectively. In contrast, an amplification of 15% of the current soil loss is predicted under the wetter climate and high emission scenario. It is noted that the amount of reduction and increment will be double in the year 2060 under the same climate scenarios. These two sub-watersheds are sensitive to changing annual rainfall because they contain steep slopes (slope greater than 30). Sub-watershed Sre Pok in Vietnam, sub-watershed Se San and sub-watershed Huai Bang Lieng in Lao PDR are less sensitive to future climate changes. The proportion of soil loss change is minimal compared with the other sub-watersheds due to more than 60% of the catchment being under forest cover.

(c) Nutrient retention

Table 3.17 shows that the estimated nutrient loadings and nutrient retentions in the entire LMB under all scenarios are not substantially different from current conditions. An increase or decrease of less than 1% respect to the current is predicted, except GS45M30 scenario. This is due to land use change is more sensitive factor to determine the variation of nutrient retention and nutrient loading in the watershed relative to the current conditions (Bhagabati *et al.,* 2014). It should be noted that the drier overall scenario reduces the amount of exported nutrients from the watershed in year 2030 because of less annual rainfalls.

Table 3.17: Changes in exported nitrogen and phosphorus from the LMB under different climate change scenarios with respect to baseline (MRC, 2017c).

Scenarios	N (%)	N (kg/yr)	P (%)	P(kg/yr)
Baseline		703752		206772
2030				
Drier overall 2.6	-0.16	-1,148	-0.20	-408
Drier overall 4.5	-1.06	-7,426	-1.12	-2,316
Drier overall 8.5	-0.66	-4,614	-0.75	-1,560
Increased seasonality 2.6	0.13	944	0.19	390
Increased seasonality 4.5	0.04	268	0.10	205
Increased seasonality 8.5	0.19	1,367	0.31	634
Wetter overall 2.6	0.17	1,204	0.17	358
Wetter overall 4.5	0.22	1,563	0.23	469
Wetter overall 8.5	0.30	2,109	0.31	637
2060				
Drier overall 2.6	0.15	1,090	0.16	323
Drier overall 4.5	-0.72	-5,095	-0.83	-1,711
Drier overall 8.5	-0.72	-5,095	-0.83	-1,711
Increased seasonality 2.6	0.15	1,090	0.16	323
Increased seasonality 4.5	0.20	1,393	0.31	650
Increased seasonality 8.5	-0.90	-6,330	-0.40	-837
Wetter overall 2.6	-0.90	-6,330	0.16	323
Wetter overall 4.5	0.20	1,393	-0.83	-1,711
Wetter overall 8.5	-0.90	-6,330	0.51	1,048

MRC (2017c) identifies a number of potential strategies to mitigate the impacts of erosion and nutrient loss on agricultural areas. These include further use of forest plantations and agroforestry including perennial fruit trees in hilly areas as well as a range of conservation practices that can be implemented at a farm-scale including residue management, crop rotation, minimum tillage and terracing on steep slopes. All of which are recommended practices regardless of the impact of climate change.

(d) Carbon storage

Projected change in carbon storage due to climate change was not examined by MRC (2017c). However, a baseline scenario was run using the InVEST model and it estimated carbon storage both above and below ground was 5,089 million tons. The tributary area Thailand was modelled as containing the highest carbon storage (8,231 million tons), followed by Lao PDR (2,204 million tons), Cambodia (1,519 million tons) and Viet Nam (463 million tons). It was noted, however, that the average carbon storage per square kilometre in Thailand was the lowest of the four MRC member countries (4,382 ton/km2) and was less than 50 per cent of the average carbon stored in Lao PDR and Cambodia due to the difference of remaining forest cover in these countries.

Summary analysis

The impacts of climate change are expected to be felt across species functional groups, including wetland and non-wetland species alike, as well as all ecoregions and for a range of different ecosystem services (MRC, 2017c). Table 3.18 illustrates the similarity in impacts across each of these elements for the three different models applied in the MRC's basin-wide impact assessments. Regardless of whether the wetter overall, drier overall or increased seasonality model is selected, for an emissions scenario of RCP4.5 to the year 2060, the maximum proportion of vulnerable species present in the LMB is the same for each functional group in each model.

Table 3.18: Summary of climate change impacts by model (wetter overall, drier overall and increased seasonality) for species vulnerability, species exposure, proportional shift in bioclimatic conditions, and ecosystem services for emissions scenario RCP4.5 to 2060 (MRC, 2017d).

Model	Maximum proportion of vulnerable species	Species exposure		Maximum, average and range in shift in ecoregions	Ecosystem services
		Wetland	Terrestrial		
Wetter overall	Amphibian: 20-40%	45%	33%	Two ecoregions at 61-70% Average: 38.5% Range: 8.7%-63.9%	↑ water yield (14%) ↓ soil (16.9%) ↑ nitrogen export (0.2%) ↓ phosphorous export (0.83%)
	Bird: 20-40%	98%	97%		
	Fish: 40-60%	30%	64%		
	Mammal: 20-40%	34%	41%		
	Reptile: <20%	38%	45%		
	Plant: 80-100%	46%	40%		
Drier overall	Amphibian: 20-40%	29%	31%	One ecoregion at 71-80% Average: 42.5% Range: 25.1%-72.2%	↓ water yield (-10%) ↑ soil (0.7%) ↓ nitrogen export (0.72%) ↓ phosphorous export (0.83%)
	Bird: 20-40%	86%	88%		
	Fish: 40-60%	22%	71%		
	Mammal: 20-40%	22%	23%		
	Reptile: <20%	23%	45%		
	Plant: 80-100%	25%	45%		
Increased seasonality	Amphibian: 20-40%	26%	38%	One ecoregion at 91-100% Average: 45.5% Range: 21.2%-92.1%	↑ water yield (9%) ↓ soil (15.8%) ↑ nitrogen export (0.20%) ↑ phosphorous export (0.31%)
	Bird: 20-40%	92%	94%		
	Fish: 40-60%	25%	14%		
	Mammal: 20-40%	64%	73%		
	Reptile: <20%	27%	64%		
	Plant: 80-100%	40%	40%		

Plant species are most significantly affected in one or more regions with some part of the basin having between 80-100 per cent of plant species considered vulnerable to climate change, while reptiles are the least affected with the maximum proportion in any area considered vulnerable less than 20 per cent. The impact on both wetland and terrestrial (or non-wetland) species is also quite similar, although the drier overall scenario appears to affect the non-wetland species more significantly than the wetland species, with fish, reptile and mammals all much more exposed than wetland species of the same functional group. Wetland species are more significantly affected in the wetter overall model for amphibians and in the increased seasonality model for fish.

For the same emissions scenario of RCP4.5 to the year 2060, the increased seasonality model produces a higher average shift in area from one bioclimatic zone to another as well as the most significant impact on a single ecoregion, where up to 100 per cent of the area shifts from one zone to another and the widest range in impacts is evident across different ecoregions, varying from 21.2 per cent to 92.1 per cent of the area shifting to different bioclimatic conditions. While the results indicate that the increased seasonality model has a bigger impact on bioclimatic conditions, followed by the drier overall and wetter overall model, it should be evident that in all cases the projected impacts are severe. Even in the wetter overall scenario the average proportion of each ecoregion that shifts bioclimatic zones is 38.5 per cent, in total some 249,871 square kilometres.

As would be expected, the wetter overall model produces an increased water yield and decreased soil loss, but with nitrogen export increasing and phosphorous export decreasing. The drier overall model produces the opposite for water yield and soil loss and a decrease in export of both nitrogen and phosphorous associated with less overall discharge from the LMB. The increased seasonality model performs similarly to the wetter overall model except in the former both nitrogen and phosphorous export increases.

These results are presented only for the emissions scenario RCP4.5 to the year 2060. However, it illustrates the impacts of climate change are likely to be very significant across species, ecoregion and for different ecosystem service regardless of whether the future is wetter, drier or one of increased seasonal effects. The results are more or less severe depending on the emissions scenario used and whether projections are extended to 2030 or to 2060.

Considering the presence of species vulnerability hotspots (Figures 3.30-3.35) it is apparent that for each of the three models, fish and plants have a higher proportion of vulnerable species than the other functional groups (Table 3.19-3.21).

Using the wetter overall model there does not appear to be any correlation between increases in temperature and precipitation by ecoregion with species hotspots. Average maximum temperature increases are projected to be fairly similar across ecoregions (1.2 to 1.6 degrees under RCP4.5 to 2060). Ecoregions with large precipitation increases do not appear any more likely to have a high proportion of vulnerable species across functional groups than ecoregions with smaller increases in precipitation.

There is also no apparent pattern evident between the proportional shift in bioclimatic zone within an ecoregion and the location of species vulnerability hotspots. There are some relatively large amphibian hotspots in the Northern Indochina subtropical forests, which experience the largest percentage shift in bioclimatic conditions and indeed there are also more fish and mammal hotspots in these northern regions. However, there are also large changes in bioclimatic conditions in some southern areas around

Tonle Sap and the Mekong Delta which do not result in similar effects. There is a high proportion of plant species vulnerable in the northern and southern areas but also in areas in between that experience relatively smaller shifts in bioclimatic conditions.

There are relatively smaller proportions of ecoregions experiencing bioclimatic shifts in much of the central part of the LMB. These areas have high species richness for fish. However, there are also high species richness of birds, fish, mammals and reptiles in areas that are projected to experience significant shifts in bioclimatic conditions (e.g. in Northern Laos and Thailand; and Tonle Sap and the Mekong Delta Region).

Table 3.19: Hotspots by ecoregion for the wetter overall model illustrating the highest proportion of species found to be vulnerable within each ecoregion (MRC, 2017d).

<20%	20-40%	40-60%	60-80%	>80%

Ecoregion	Amphibians	Birds	Fish	Mammals	Reptile	Plants
Cardamom Mountains rain forests						
Kayah-Karen montane rain forests						
Luang Prabang montane rain forests						
Northern Annamites rain forests						
Northern Indochina subtropical forests						
Northern Khorat Plateau moist deciduous forests						
Northern Thailand-Laos moist deciduous forests						
Northern Vietnam lowland rain forests						
Southern Annamites montane rain forests						
Tonle Sap freshwater swamp forests						
Tonle Sap-Mekong peat swamp forests						
Central Indochina dry forests						
Southeastern Indochina dry evergreen forests						
Indochina mangroves						

As with the wetter overall model, there does not appear to be any relationship between increases in temperature by ecoregion with species hotspots for the drier overall or increased seasonality models. The average maximum temperature increases are fairly similar across ecoregions (1.2 to 1.6 degrees under RCP4.5 to 2060).

Under the drier overall model ecoregions with large precipitation decreases do not appear any more likely to have a high proportion of vulnerable species across functional groups than ecoregions with smaller increases in precipitation. Although none of the three ecoregions with the smallest decrease in precipitation (Indochina Mangroves, Kayah-Karen Montane Rain Forests, and Tonle Sap-Mekong Peat Swamp Forests) have any hotspots with greater than 40 per cent of species vulnerable, some ecoregions with large precipitation decreases similarly have hotspots with no more than 40 per cent of species considered vulnerable to climate change (e.g. Northern Annamites rain forests and Northern Khorat plateau moist deciduous forests).

As with the wetter overall model there is no apparent pattern evident between the proportional shift in bioclimatic zone of each ecoregion and the location of hotspots. There are some relative large amphibian hotspots along the western boundary of the LMB and especially in the north and around Tonle Sap, where a very large portion of the ecoregion experiences a shift in bioclimatic conditions (71-80%); but there are also hotspots in areas with relatively smaller proportions of the ecoregion experience a shift in bioclimatic conditions (e.g. Northern Annamites rain forests). There are some hotspots of bird vulnerability around Tonle Sap where large shifts in bioclimatic conditions occur, but less so in northern parts of the LMB. Mammals are vulnerable in northern parts of the basin, but both in areas experiencing higher and lower proportional shifts in bioclimatic conditions.

Table 3.20: Hotspots by ecoregion for the drier overall model illustrating the highest proportion of species found to be vulnerable within each ecoregion (MRC, 2017d).

<20%	20-40%	40-60%	60-80%	>80%

Ecoregion	Amphibians	Birds	Fish	Mammals	Reptile	Plants
Cardamom Mountains rain forests						
Kayah-Karen montane rain forests						
Luang Prabang montane rain forests						
Northern Annamites rain forests						
Northern Indochina subtropical forests						
Northern Khorat Plateau moist deciduous forests						
Northern Thailand-Laos moist deciduous forests						
Northern Vietnam lowland rain forests						
Southern Annamites montane rain forests						
Tonle Sap freshwater swamp forests						
Tonle Sap-Mekong peat swamp forests						
Central Indochina dry forests						
Southeastern Indochina dry evergreen forests						
Indochina mangroves						

There is a relatively lower proportion of the eastern boundary of the LMB projected to experience bioclimatic shifts (including the Northern and Southern Annamites Montane rain forests) and through the Luang Prabang Montane rain forests region. These areas have high species richness for amphibians, birds, mammals, fish and reptiles. However, there are also high species richness of birds, fish, mammals and reptiles in areas that are projected to experience significant shifts in bioclimatic conditions (Northern Laos and Thailand; and Tonle Sap and the Delta Region).

Under the increases seasonality model ecoregions with large precipitation increases or decreases do not appear any more likely to have a high proportion of vulnerable species across functional groups than ecoregions with smaller increases in precipitation.

Table 3.21: Hotspots by ecoregion for the increased seasonality model illustrating the highest proportion of species found to be vulnerable within each ecoregion (MRC, 2017d).

<20%	20-40%	40-60%	60-80%	>80%

Ecoregion	Amphibians	Birds	Fish	Mammals	Reptile	Plants
Cardamom Mountains rain forests						
Kayah-Karen montane rain forests						
Luang Prabang montane rain forests						
Northern Annamites rain forests						
Northern Indochina subtropical forests						
Northern Khorat Plateau moist deciduous forests						
Northern Thailand-Laos moist deciduous forests						
Northern Vietnam lowland rain forests						
Southern Annamites montane rain forests						
Tonle Sap freshwater swamp forests						
Tonle Sap-Mekong peat swamp forests						
Central Indochina dry forests						
Southeastern Indochina dry evergreen forests						
Indochina mangroves						

There is also no apparent pattern evident between the proportional shift in bioclimatic zone and the location of species vulnerability hotspots. There are relatively lower proportions of ecoregions along the east and west boundaries of the basin (including the Northern and Southern Annamites Montane rain forests and Cardamom Mountains rain forests) projected to experience bioclimatic shifts. These areas have high species richness for amphibians, birds, mammals and reptiles. However, there are also high species richness of mammals, birds, and reptiles in areas that are projected to experience large shifts in bioclimatic conditions.

Under all models it is not possible to link the proportion of vulnerable species with ecoregions projected to experience the most significant perturbation. This is possibly because all ecoregions are projected to experience very significant change by 2060. The increased seasonality model for example, shows changes in bioclimatic conditions from 21.2 per cent of the area up to 92 per cent under the RCP4.5 scenario. These changes mean a high proportion of species, especially plants and fish, are vulnerable to climate change. While the proportion of ecoregions that shift bioclimatic zones under the RCP4.5 scenario is lower for the wetter overall and drier overall models, the impacts are still large, and fish and plants are the functional groups where the largest proportion of species is affected. Reptiles and to a lesser extent amphibians and mammals generally have a smaller proportion of species vulnerable to climate change across ecoregions.

The traits that make species more vulnerable to climate change are largely similar whether or not the species are wetland or terrestrial (non-wetland) species. For amphibians, both wetland and non-wetland species have similar traits that make them sensitive to climate change. The most significant traits are an intolerance of drought and dependence on an environmental trigger for some critical life-cycle process. In addition, non-wetland species are also more likely to be dependent on one or more micro-habitats.

For birds, wetland species are more likely to be intolerant of fire regime changes and dependent on environmental triggers for key lifecycle processes, whereas non-wetland species are more likely to be intolerant of precipitation regime changes. For fish, wetland species are more likely to be intolerant of precipitation regime changes, dependent on flood regime and have migration limited by water level changes, whereas non-wetland species are more likely to be habitat specialists and intolerant of temperature regime changes.

For mammals, wetland species are more likely to be intolerant of precipitation regime changes whereas non-wetland species are more likely to be intolerant of temperature regime changes and be habitat specialists. For reptiles, wetland species are more likely to be intolerant of drought whereas non-wetland species are more likely to be intolerant of temperature and precipitation regime changes and to be dependent on a particular environmental trigger for some important lifecycle process. For plants, wetland and non-wetland species share similar sensitivity traits, although non-wetland species are more likely to include habitat specialisation and intolerance of drought as reasons for sensitivity to climate change.

For all functional groups, the adaptive capacity traits that are most significant for wetland species are the same as for non-wetland species, except for fish, where wetland species are more likely to have extrinsic barriers to dispersal and non-wetland species to have low reproductive output. For amphibians and reptiles both wetland and non-wetland species the most significant adaptive capacity traits are low intrinsic dispersal capacity and low reproductive output. For birds and mammals both wetland and non-wetland species, the most significant adaptive capacity traits are extrinsic barriers to dispersal and low reproductive output. For plants, both wetland and non-wetland species, the most significant adaptive capacity traits are low intrinsic dispersal capacity and low genetic diversity.

3.4 Fisheries

Key findings

No significant impacts on fisheries have been attributed to climate change to-date. Mekong fisheries are highly productive and in the shorter term are likely to be more significantly impacted by threats such as flow modification due to dams and intensification of agricultural activity than by climate change. While overall yields have increased, catch per unit of effort appears to be declining indicating more people chasing fewer fish. As identified in section 3.3 fish species of the LMB are vulnerable to potentially large changes in flow and water level over time. They are also vulnerable to changes in salinity intrusion due to sea level rise, and increased temperatures. Projected impacts on fisheries could be positive or negative depending on the scenario, although with those dependent on flood zone habitats likely to experience greater changes than those in rice paddy habitats. Despite their apparent vulnerability only minor impacts on aquaculture productivity are expected due to a significant number of Delta provinces being unaffected by salinity intrusion.

3.4.1 Past and current conditions

Basin-wide fisheries yield is estimated to vary between 1.3 and 2.7 million tonnes per year (MRC, 2015e), a figure which is consistent with previous estimates of basin-wide consumption of wild-caught fish and Other Aquatic Animals (OAAs) of 2.37 million tonnes per year (Hortle, 2007), and within the range previously estimated based on wetland data of 0.7-2.9 million tonnes per year (Hortle, 2007). MRC (2015e) identified a 'most likely' LMB yield estimate for each of three habitat zones in each Member Country based on their areas and an assumed yield per unit area from each habitat zone (Table 3.21).

The 'most-likely' yield is largely consistent with the consumption-based estimate (2.3 million tonnes per year), so it provides a basis for attributing yield to the different broad habitat zones. Under this working hypothesis of the LMB yield, equal proportions (45%) derive from river-floodplain habitats in the major flood zone (moderate-high yield over a moderate area) and from rice fields and associated habitats in the rain-fed zone (low-moderate yield over a very large area), with a minor contribution (about 10%) from reservoirs and other large permanent waterbodies outside the major flood and rain-fed zones. This assessment does not include separate yield information from the estuarine zone and so is probably conservative for some habitats.

River floodplain habitats within the major flood zone are likely to be threatened by reduced flooding and the installation of structures which inhibit movement of aquatic animals across the floodplain and along the river. The main threats to rain-fed habitats are likely to be from intensified agriculture involving the use of high-yielding varieties associated with shallower water depths and accompanied by increasing use of pesticides. Reservoirs have been a successful focus for co-management in the past and fisheries production can be enhanced by measures such as stocking, catch regulations, catchment management and protection of spawning streams, and management of reservoir operations.

Catch composition of capture fisheries in the LMB is dominated by two fish families: Cyprinidae (minnows and carps) and Pangasiidae (shark catfishes). Results from MRC monitoring programmes since the late 1990s indicate that fishes from these two families contributed around 85 per cent of total reported catches. Ten fish species which make up around 98 per cent of the total catch are given in Figure 3.37.

Table 3.21: Estimates of basin-wide yield and the estimated range of yields per unit area (kt/year) (MRC, 2015e).

Low-Yield estimate

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 River-floodplain: Within the major flood zone @ 100 kg/ha/yr	283	46	78	173	0	580
2 Rainfed Outside the major flood zone @ 50 kg/ha/yr	88	45	466	43	8	649
3 Large waterbodies (mainly reservoirs) Outside the flood zone @ 100 kg/ha/yr	9	21	35	8	2	75
Total Low Estimate	**379**	**112**	**579**	**225**	**9**	**1,304**

Medium-yield estimate

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 River-floodplain: Within the major flood zone @ 150 kg/ha/yr	424	69	117	260	0	870
2 Rainfed: Outside the major flood zone @ 75 kg/ha/yr	132	67	698	64	12	974
3 Large waterbodies: (mainly reservoirs) Outside the flood zone @ 200 kg/ha/yr	17	43	70	17	3	150
Total Low Estimate	**573**	**179**	**886**	**341**	**15**	**1,994**

High-yield estimate

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 River-floodplain: Floodplain within the major flood zone @ 200 kg/ha/yr	565	92	156	347	0	1,160
2 Rainfed: Outside the major flood zone @ 100 kg/ha/yr	176	90	931	86	16	1,298
3 Large waterbodies: (mainly reservoirs) outside the flood zone @ 300 kg/ha/yr	26	64	106	25	5	225
Total High Estimate	**767**	**246**	**1,193**	**458**	**20**	**2,684**

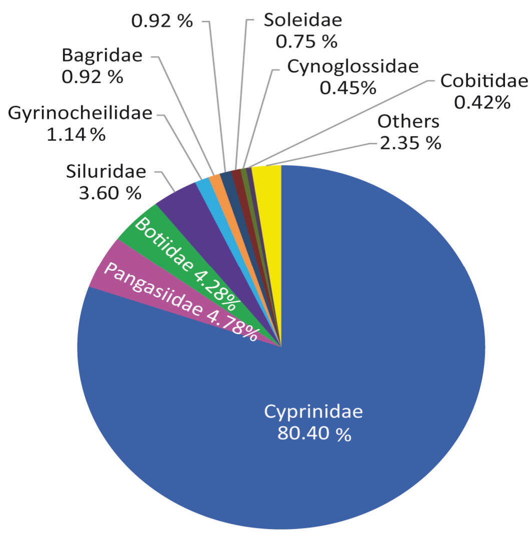


Figure 3.37: Fish catch composition of top ten fish species in LMB recorded by MRC fisheries monitoring programmes (MRC, 2015e).

Trends in capture fisheries in the Mekong mainstream and its major tributaries fisheries

Under the Mekong River Commission's Fish Abundance and Diversity Monitoring Programme, fishers report catches and fishing effort from a number of fisheries in different habitats in each of the four LMB countries. At least 26 types of fishing gear were reported in this monitoring programme. Gillnets were the type of gear most commonly used by fishers within all major habitat types and during most months in all four countries. Data on stationary gillnets from some selected monitoring locations in the LMB and some major tributaries illustrate downward trends in average catch at six of the eight sites (MRC, 2016a):

1. Ou Run, Mekong River, Stung Treng Province, Cambodia;
2. Koh Khnhe, Mekong River, Kratie Province, Cambodia;
3. Pres Bang, Sekong River, Stung Treng Province, Cambodia;
4. Day Lo, Sre Pok River, Ratanakiri Province, Cambodia;
5. Ban Pha O, Mekong River, Luang Prabang, Lao PDR;
6. My Thuan, Mekong River, An Giang Province, Viet Nam.

Increases in average catch are reported at one site: Fang, Sesan River, Ratanakiri Province, Cambodia; and are stable at one site: Ban Hat, Mekong River, Champassak, Lao PDR. There is no indication that these trends are a result of climate change.

The *lee trap* fishery has been monitored since 1994 with the MRC Fisheries Programme supporting monitoring by the Living Aquatic Resources Research Centre (LARReC) since 2005. Halls *et al.* (2013) recorded catch and effort of the fishery since 2008. As reported in MRC (2016a), the average catch rate of the fishery was highest in 2005 at 51 kg per lee trap per day. The average catch rate dropped sharply to only 18 kg in 2006 and continued to decrease until 2013.

The MRC and the Cambodian Fisheries Administration have been monitoring the *dai* fishery on the Tonle Sap River since the 1995-96 season. The fishery targets small mud carps migrating downstream from the Tonle Sap Lake from the end of the wet season in October to March. Established about 140 years ago, the stationary bagnet fishery is a very useful indicator of Cambodia's inland fisheries and could also be a good indicator of overall Mekong fisheries and their ecological health. Changes in the size of catches since 1995 (Figure 3.38) largely reflect the impact of annual floods on fish growth (Halls *et al.,* 2013a; 2013b; Ngor *et al.,* 2015).

Although there is no compelling evidence of a decline in biomass, fish weight or species competition attributable to increased fishing pressure in response to a growing population (Halls *et al.,* 2013a), catches of some large and medium-sized species were found to have declined between 1998 and 2014 (Ngor *et al.,* 2015). By contrast, catches of small mud carps trended upwards over the same period. At the same time, the total lengths of some fish have been declining. This may indicate declining production of large high-value species accompanied by increased production of small low-value species that are short lived.

While factors behind declining catches of some large and medium-sized fishes may include increased fishing effort, hydrological and hydraulic changes, habitat degradation, loss of habitat connectivity and climate change, it has not been possible to definitively attribute changes to any one or a combination of these factors. It is also not possible to determine conclusively whether changes in catch or yield are a result of changes in the underlying fish populations or are due to other factors such as fishing pressure through changes in gear and effort. SIMVA 2014 (MRC, 2015e) identifies that catch per unit effort has declined in recent years.

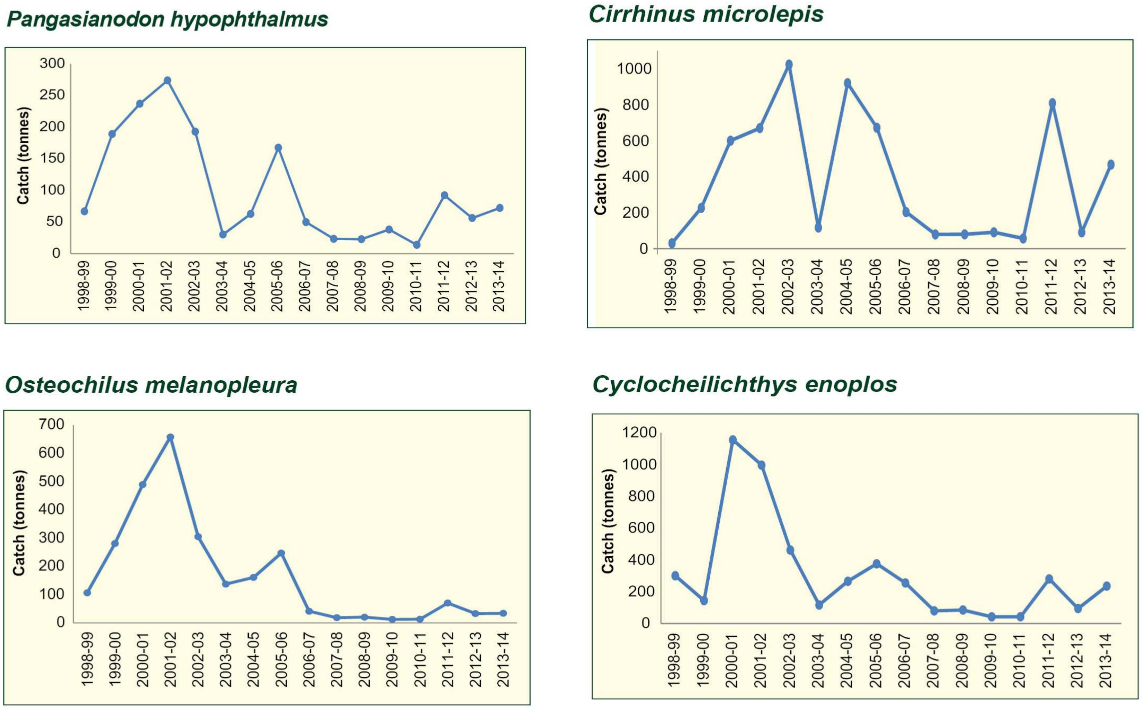


Figure 3.38: Catch trends of large and medium-size fish species at the *dai* fishery, Tonle Sap River (Ngor *et al.*, 2015).

USAID (2013) note that the number of fish species in the LMB is estimated to be between 500 and 1,200 although some estimates put it as high as 2,000. The biodiversity and productivity of the fishery is strongly linked to the annual flood pulse and the connectivity that this provides between a range of natural habitats and artificial habitats. The flood pulse allows for the migration of fish between feeding, spawning and resting habitats while also inundating terrestrial food sources and liberating nutrients from sediments (USAID, 2013). As a result, catches tend to show seasonal trends related to water level, flow and fish migration with catches higher at the beginning of the wet season (June-July) and at the end of the wet season (November-December). Climate change impacts on the hydrology of the Mekong Basin could have significant impacts on the biodiversity and productivity of Mekong fisheries.

Changes to habitat temperature may influence metabolism, growth rate, production, reproduction, recruitment, and susceptibility to toxins and disease, affecting the ranges of some species thereby reducing biodiversity in some areas (USAID, 2013). Lower dissolved oxygen levels and increased phytoplankton populations could also shift the species mix. Changes in rainfall may affect fish through impacts on the annual flood pulse, but also through extended dry spells reducing floodplain habitats. Increased sea-levels and increased storm intensity and frequency may reduce habitat and lead to periodic fish kills due to salinity intrusion. In summary, USAID (2013, p.151) identify that:

- Upland fish will be the most vulnerable to climate change
- Migratory white fish will be vulnerable to climate change

- Black fish will by more 'climate-proof' than other types of fish; and
- Invasive species will become more prevalent due to climate change.

3.4.2 Projected climate change impacts

As summarised in MRC (2016f) climate change is expected to impact on fish through several mechanisms including through alterations to the hydrological (flood) regime, an increase in temperature and sea level rise (Table 3.22). Fish yield in the LMB is directly related to the magnitude of the annual flood with higher floods generally leading to higher yields (Halls *et al.,* 2013). Conversely increased drought intensity and frequency could have a negative impact on fish populations (Ficke *et al.,* 2007).

Sea level rise can impact on fish through salt water intrusion. Studies on the tolerance of aquaculture species most common in the Delta have shown that they tolerate water salinity up to 13 ppt without any effects on growth rates, but their survival rate declines drastically (over 60%) once salinity is greater than 20 ppt (Halls and John, 2013 after Castenada *et al.,* 2010).

There is not much known about the effects of temperature rises on tropical fish including in the Mekong. However, fish energy use is expected to become less efficient with rising temperatures and higher temperatures can also increase the toxicity of pollutants in the water (MRC, 2016f).

Table 3.22: Summary of drivers and effects of impacts of climate change on wild fisheries and aquaculture. Arrows highlight presume direction (positive or negative) for catches (MRC, 2016f).

Climate drivers	Wild fish	Aquaculture
Flood alterations	• Increased success of invasive species (-) • Altered recruitment (-/+) • Allochthonous input of material into the aquatic system (-/+) • Affect extent of habitats (-/+)	• Episodic disease and predator introduction (-) • poor water quality during drought (-) • escape of stock (-)
Increase Temperature	• Expanded habitat suitability northward (+) • Decrease metabolic energy efficiency (-) • Increase primary productivity (+)	• Higher disease risk (-) • Increase toxicity of pollutants (-)
Sea level rise	• Loss of nursery ecosystems (-)	• Altered water chemistry (-) • Loss of optimal area (-) • Damage with storm surges (-)

ICEM (2010) considered that the potential impacts of climate change on fisheries could include:

- Increased productivity due to:
  - increased runoff and erosion leading to increased sediment and organic load in waterways
  - greater flooded area and therefore more habitat
- Decreased productivity due to:
  - More constrained movement and resources in drier dry seasons
  - Reduced habitat due to greater flooded area
  - Increased water temperatures affecting fish physiology, particularly reproduction
  - Flooding of aquaculture ponds
- Increased variability due to:
  - Increased hydrological variability

- Saltwater intrusion good for brackish and marine species but not good for freshwater species

Mainuddin *et al.* (2012) applied an empirical fisheries model to simulate the impact of climate change and hydropower development on the fish productivity of the Tonle Sap Lake system, taking into account only the impacts of changing flow patterns. Their results suggest that fish biomass during the next 40 years is unlikely to be affected by climate change. However, they did not consider impacts such as changes in water temperatures or salinity.

Aquaculture is considered more vulnerable to climate change than capture fisheries (USAID, 2013), although also has high adaptive capacity due to high management inputs and extension supports. Intensive systems look particularly vulnerable in lowland and coastal areas. While aquaculture may become possible or more viable in new (higher elevation) areas, this is unlikely to compensate for the production losses from lowland areas (USAID, 2013)

Kam *et al.* (2012) conclude that projected temperature rises are within the tolerance ranges of major cultivated shrimp and catfish species. However, there could still be impacts including as a result of higher organic decomposition rates and lower dissolved oxygen. A wetter climate could lead to increased disease risk and use of antibiotics, while increased sea-levels could lead to salinity intrusion and more flooding and storm surges.

Projected impacts on capture fisheries

Applying the same model as MRC (2015e), MRC (2016f) undertook an assessment of projected climate change impacts on fisheries as a result of changes to fish habitat, specifically flood area habitat and rice paddy habitat. Depending on the scenario selected, the change in area of the flood zone varied from -5922 km^2 (-13%) to +6293 km^2 (+13.7%) by 2060 with no development, while changes in the area of rice paddy habitat varied from -3597 km^2 (-2.7%) to +3043 km^2 (+2.3%). As yield per area was determined for each habitat type the change in yield varied in a similar way (Table 3.23).

Total fish yields from the flood zone in the LMB during the baseline period were estimated at 458,000-917,000 tons annually, and fish yields from rice paddies were estimated at 672,000-1,345,000 tons per year. This provided a total wild fish yield of 1,206,000 to 2,488,000 tons per year (including production in reservoirs, assumed to be constant for all scenarios), which is consistent with the estimates from MRC (2015e) as provided in Table 3.21. Given the shifts in habitats the magnitude of changes in fish yields are expected to be greater for the flood zone than in the rice paddies. Considering scenarios with no development alone, for instance, yields in the flood zone are expected to change by -60,000 to +125,000 tons yr^{-1} (-13 to +9%), compared to changes by -18,000 to +30,000 tons yr^{-1} (-3 to +2%) in yields from rice paddies.

Table 3.23: Changes in total fish yields as a function of shifts in habitats for three modelled scenarios (wetter overall,drier overall, and increased seasonal variability), two resource concentration pathways (RCP4.5 and RCP8.5), to 2030 and 2060. Results are given for climate change impacts only and for climate change and development impacts together (MRC, 2016f).

Scenario description	Total fish yield (kt/yr)			Change from baseline (ktons/yr)			Change from baseline (%)		
	Flood zone	Rice paddies	Total	Flood zone	Rice paddies	Total	Flood zone	Rice paddies	Total
Baseline	458 to 917	672 to 1345	1206 to 2488	-	-	-	-	-	-
Scenarios with no development									
2030									
Wetter overall 4.5	467 to 934	670 to 1340	1212 to 2500	8 to 16	-3 to -5	6 to 12	2	0	0
Drier overall 4.5	437 to 874	679 to 1358	1191 to 2458	-22 to -44	6 to 12	-16 to -31	-5	1	-1
Increased seasonality 4.5	467 to 934	670 to 1340	1212 to 2500	8 to 16	-3 to -6	5 to 11	2	0	0
Wetter overall 8.5	487 to 974	664 to 1329	1227 to 2529	28 to 56	-9 to -17	20 to 40	6	-1	2
Drier overall 8.5	420 to 840	684 to 1368	1179 to 2433	-39 to -78	11 to 22	-28 to -55	-8	2	-2
2060									
Wetter overall 4.5	499 to 999	661 to 1323	1236 to 2547	40 to 81	-12 to -23	29 to 58	9	-2	2
Drier overall 4.5	437 to 874	679 to 1358	1191 to 2457	-22 to -44	6 to 12	-16 to -32	-5	1	-1
Increased seasonality 4.5	477 – 954	667 to 1334	1219 to 2513	18 to 36	-6 to -12	12 to 24	4	-1	1
Wetter overall 8.5	521 to 1043	654 to 1309	1251 to 2578	62 to 125	-18 to -36	44 to 89	14	-3	4
Drier overall 8.5	399 to 799	688 to 1376	1162 to 2400	-60 to -119	15 to 30	-45 to -89	-13	2	-4
Scenarios with development									
2030									
Wetter overall 4.5	485 to 971	665 to 1330	1225 to 2526	26 to 53	-8 to -16	18 to 37	6	-1	2
Drier overall 4.5	377 to 755	695 to 1390	1148 to 2371	-82 to -163	22 to 44	-59 to -118	-18	3	-5
Increased seasonality 4.5	414 to 828	685 to 1370	1174 to 2424	-45 to -90	12 to 25	-33 to -65	-10	2	-3
Wetter overall 8.5	501 to 1002	660 to 1320	1236 to 2547	42 to 84	-13 to -26	29 to 58	9	-2	2
Drier overall 8.5	353 to 707	700 to 1401	1129 to 2334	-106 to -211	27 to 55	-78 to -155	-23	4	-6
2060									
Wetter overall 4.5	480 to 960	667 to 1334	1222 to 2519	21 to 42	-6 to -12	15 to 30	5	-1	1
Drier overall 4.5	424 to 849	682 to 1365	1182 to 2439	-35 to -69	9 to 19	-25 to -50	-8	1	-2
Increased seasonality 4.5	483 to 967	665 to 1330	1224 to 2523	24 to 49	-8 to -15	17 to 34	5	-1	1
Wetter overall 8.5	527 to 1054	653 to 1306	1255 to 2585	68 to 136	-20 to -40	48 to 97	15	-3	4
Drier overall 8.5	385 to 770	691 to 1382	1151 to 2377	-74 to -148	18 to 36	-56 to -112	-16	3	-5

Cumulative changes in total fish yields as a result of shifts in both habitat types lead to a net change of -155,000 tons yr^{-1} (-6% from baseline) to +97,000 tons yr^{-1} (+4%) for all future scenarios. For scenarios with no future development, very small changes (-31,000 to +12,000 tons yr^{-1}) were estimated in the short term (2030s) for medium sensitivity (RCP 4.5) scenarios for all 3 GCMs, and only minor changes (±2% from baseline) for high sensitivity (RCP 8.5) scenarios. The magnitude of change doubled for the medium term scenarios, for which expected changes range from -89,000 to +89,000 tons yr^{-1} (-13 to + 14 of total baseline yield). When development scenarios are considered, it appears that there are likely to be much more detrimental conditions in the short term, with more than a three-fold increase in changes (-118,000 to +65,000 tons yr^{-1}) when compared to the scenarios with no development. Conversely, scenarios for the medium term with development are much more similar to their counterparts without development, and even smaller in the case of the wetter overall scenario with medium climate sensitivity.

Arguably the most important limitation of this analysis is the assumption of a constant fish yield rate per habitat (MRC, 2016f). This limitation was partially overcome by carrying out the calculations for a range of values (50-100 tons/ha/yr in rice paddies, and 100-200 tons/ha/yr in the flood zone) that broadly represent the variability in these rates. Still, it is unlikely that these rates are constant from region to region and from time to time. Even when focusing on one particular habitat, there are probably a large number of environmental and management factors that would promote or discourage fish production on a particular location. What is more important, it is probable that these rates change –in addition to the extent of habitats as it was evaluated in this assessment– change in the future as a function of climate drivers and development practices. Moreover, the overly simplistic method to estimate fish yields – which for consistency was adapted from a recent MRC (MRC, 2015e) study – does not take into account other important climate-driven factors such as flood level and derived indicators, which have been shown to significantly affect particular fisheries in the LMB (Halls *et al.,* 2013).

Projected impacts on aquaculture

An assessment of projected climate change impacts on aquaculture production was undertaken by examining the effect of salinity intrusion on the Delta region and a calculation of potential productivity per usable area of land for aquaculture (MRC, 2016f). This analysis focused on the baseline year of 1998 and productivity at a provincial level based on production in the year 2010 as the baseline. Impacts of salt intrusion on aquaculture production were assessed by assuming that an increase in the provincial area with a maximum salinity above 20 ppt will have an inversely proportional decrease in aquaculture production.

Overall most scenarios of climate change show minor losses (1 to 6%) in delta-wide aquaculture production compared to baseline conditions (Table 3.24). The only exceptions to this are the two scenarios of medium-term horizon with high climate sensitivity and development (wetter overall and RCP8.5 and drier overall and RCP 8.5 for 2060), which show an increase in the total Delta production by 10-11 per cent (MRC, 2016f). Delta-wide changes to aquaculture, however, are not expected to be evenly distributed among provinces, and a great proportion of the expected changes can be tracked to only a few provinces. On the one hand, losses in Ca Mau (an average loss of 59,148 tons yr^{-1} for scenarios with no development, or 59% of baseline production) alone could be up to ten times higher than at the next most affected province, Soc Trang (average loss of 5,852 tons yr^{-1} for scenarios with no development). On the other hand, Ben Tre is expected to be favoured in the future, with a potential increase in production by 6,831-94,416 tons yr^{-1} in all but one scenario (medium term horizon of a drier climate with high sensitivity). Furthermore, since no changes in acute salinity were estimated for Dong Thap, An Giang, Can Tho, and Vinh Long, where 23%, 20%, 12%, and 9% of the current Delta's aquaculture production take place, respectively, a majority of the delta-based aquaculture could in fact be unaffected by the simulated future acute salinity extent into the floodplains.

A number of assumptions were made in order to carry out this analysis (MRC, 2016f) and provide meaningful estimates given the data and modelling results that were available. First, it was assumed that there is no sensitivity to multi-year variability in climate and salt intrusion dynamics. This is an important factor to consider, given that the most tangible effect of climate change in the Mekong region may be an increase in variability, rather than trends in average environmental variables. In order to overcome this assumption, however, historical climate data and time series modelling results of salt intrusion would have been necessary, but unfortunately those data were not available at the time. Even if that information was available, it is difficult to infer climate sensitivity from the aquaculture time series, because of the exponential growth that the aquaculture industry experienced during the period of record that were most likely driven by financial investments and technological improvements in the industry, rather than any climate factors.

Another important assumption that was made in this assessment relates to the sensitivity of aquaculture species to salinity. Clearly, different fish species may have different tolerances to salinity, hence this study provide a range of changes in salinity intrusion zones, and inferences on changes to aquaculture production were only made based on the salinity level that is well known to cause biological limitation to relevant freshwater aquaculture species relevant to the Mekong Delta. Another factor related to salt intrusion that was not incorporated in the assessment is the interplay of salinity with other water quality indicators, which may influence fish biology (Ficke *et al.*, 2007) and hence aquaculture production.

Table 3.24: Estimated changes in aquaculture production proportional to extent of salt intrusion greater than 20 ppt (acute impact to aquaculture) for three modelled scenarios (wetter overall,drier overall, and increased seasonal variability), two resource concentration pathways (RCP4.5 and RCP8.5), to 2030 and 2060. Results are given for climate change impacts only and for climate change and development impacts together. Dong Thap, An Giang, Can Tho, or Vinh Long absent from table as no salt intrusion at this acute concentration expected in these provinces (MRC, 2016f).

	Tien Giang	Kien Giang	Ben Tre	Tra Vinh	Soc Trang	Bac Lieu	Ca Mau	All provinces
Aquaculture production 2010 (tons)	87925	46637	124850	53823	63440	63814	108963	1489671
Province area (km²)	1716	5756	2255	2302	3298	2348	5208	34339
% area of acute salinity baseline year	4	0	37	0	8	34	53	14
Production per usable land (ton/km²)	53	8	88	23	21	41	44	
Changes in aquaculture production proportional to losses in usable land, tons/yr (%)								
No development scenarios								
2030								
Wetter overall 4.5	-148 (-1)	-1007 (-3)	14889 (11)	-144 (-1)	-6694 (-11)	-5765 (-10)	-66283 (-61)	-65148 (-5)
Drier overall 4.5	-405 (-1)	-1616 (-4)	11070 (8)	-150 (-1)	-6810 (-11)	-5732 (-9)	-67169 (-62)	-70809 (-5)
Increased seasonality 4.5	-209 (-1)	-907 (-2)	13498 (10)	-150 (-1)	-6257 (-10)	-1313 (-3)	-59882 (-55)	-55217 (-4)
Wetter overall 8.5	-113 (-1)	-1152 (-3)	14443 (11)	-148 (-1)	-6593 (-11)	-4307 (-7)	-65711 (-61)	-63578 (-5)
Drier overall 8.5	-620 (-1)	-1730 (-4)	8026 (6)	-161 (-1)	-7471 (-12)	-5945 (-10)	-67528 (-62)	-75428 (-6)
2060								
Wetter overall 4.5	213 (0)	-2562 (-6)	17062 (13)	-150 (-1)	-4985 (-8)	-1028 (-2)	-57452 (-53)	-48900 (-4)
Drier overall 4.5	-620 (-1)	-1686 (-4)	6830 (5)	-164 (-1)	-6841 (-11)	-4340 (-7)	-66756 (-62)	-73573 (-5)
Increased seasonality 4.5	-269 (-1)	-1523 (-4)	11460 (9)	-154 (-1)	-6448 (-11)	-4285 (-7)	-66340 (-61)	-67557 (-5)
Wetter overall 8.5	-56 (-1)	-1893 (-5)	17009 (13)	-155 (-1)	-5848 (-10)	-4163 (-7)	-66885 (-62)	-61988 (-5)
Drier overall 8.5	-390 (-1)	-8 (-1)	-4042 (-4)	3 (0)	-574 (-1)	-305 (-1)	-7480 (-7)	-12794 (-1)
Development scenarios								
2030								
Wetter overall 4.5	247 (0)	-977 (-3)	19143 (15)	-140 (-1)	-5913 (-10)	-6008 (-10)	-68390 (-63)	-62035 (-5)
Drier overall 4.5	-154 (-1)	-1741 (-4)	13558 (10)	-152 (-1)	-6674 (-11)	-7551 (-12)	-67669 (-63)	-70379 (-5)
Increased seasonality 4.5	-32 (-1)	-1655 (-4)	15406 (12)	-150 (-1)	-6578 (-11)	-7412 (-12)	-67656 (-63)	-68075 (-5)
Wetter overall 8.5	370 (0)	-1003 (-3)	21437 (17)	-137 (-1)	-5981 (-10)	-6534 (-11)	-68717 (-64)	-60561 (-5)
Drier overall 8.5	-531 (-1)	-1731 (-4)	9230 (7)	-159 (-1)	-7245 (-12)	-7829 (-13)	-68109 (-63)	-76372 (-6)
2060								
Wetter overall 4.5	-184 (-1)	-1038 (-3)	14942 (11)	-153 (-1)	-5712 (-10)	-5152 (-9)	-67701 (-63)	-64994 (-5)
Drier overall 4.5	-418 (-1)	-1791 (-4)	11226 (8)	-166 (-1)	-6872 (-11)	-8717 (-14)	-70033 (-65)	-76769 (-6)
Increased seasonality 4.5	138 (0)	-1576 (-4)	18191 (14)	-152 (-1)	-6176 (-10)	-6742 (-11)	-68315 (-63)	-64630 (-5)
Wetter overall 8.5	3728 (4)	-1039 (-3)	94416 (75)	-141 (-1)	-238 (-1)	27048 (42)	52879 (48)	176656 (11)
Drier overall 8.5	2959 (3)	-2041 (-5)	78291 (62)	-131 (-1)	-1640 (-3)	27091 (42)	52830 (48)	157361 (10)

Chapter 4: Implications of climate change for socio-economic conditions

4.1 Agriculture and irrigation

Key findings

Agriculture production has been growing strongly in LMB countries, at the same time as it has become a less significant contributor to GDP and employment. While floods and droughts and other extreme events can have significant negative impacts on agricultural production, no significant impacts have been directly attributed to long-term climate change to-date. Projected impacts may be either positive or negative depending on the area concerned, but overall yields for some crops such as rice and maize may decline without changes in agricultural practice and technological improvements. The projected impacts of climate change on yields are expected to be negative for both rice and maize with bigger impacts on rice than maize. Overall production of important crops and livestock are still forecast to increase, particularly as a result of new irrigation development, but the growth may be lower than it otherwise would have been.

4.1.1 Past and current conditions

In 2013, agriculture, fisheries and forestry represented 20 per cent (northeast Thailand) to 34 per cent (Cambodia) of the Basin's economy. Although agriculture's contribution to GDP is gradually falling and projected to continue falling into the future (Figure 4.1), agriculture and fisheries continue to be the most significant employer within rural areas of the Basin. The Basin's production contributes to the substantial agricultural exports and agricultural trade surpluses of Thailand and Viet Nam in particular. In 2011, national agriculture exports in Thailand were US$ 37 billion with a trade surplus of US$27 billion. In Viet Nam the figures were US$14 billion and US$ 2 billion, respectively (MRC, 2016a).

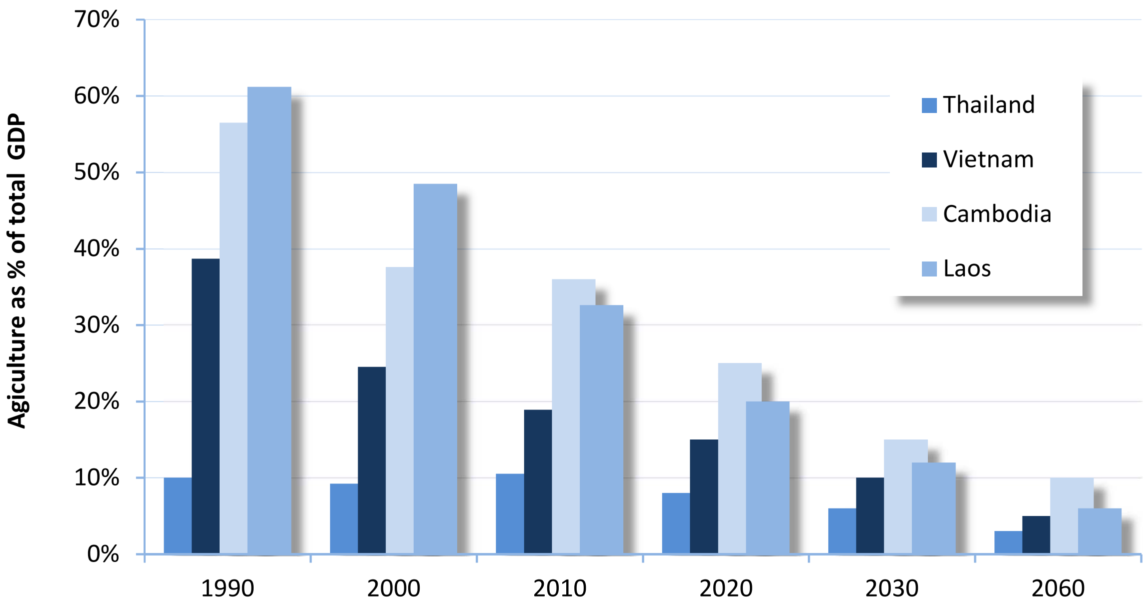


Figure 4.1: Contribution of agricultural sectors as a % of GDP in LMB countries (MRC, 2016a*).*

It is expected that agriculture and aquaculture will continue to be a major export earner and supplier of domestic food needs across the region. Its contribution to the basin's economy will, however, continue to decline in percentage terms. The LMB's comparative advantage in food production will provide growing opportunity for commercial agricultural enterprises to benefit from rapidly rising global demand for food (MRC, 2016a).

With regard to the contribution of the agricultural sector to employment, a very substantial proportion of the population were dependent on the agricultural sector for their livelihood in 1990; ranging from 63% in Thailand to 85% in Lao PDR. Between 1990 and 2010, there was a decline in contribution of the agricultural sector but, by 2010, the population depending on agriculture and fisheries was still high; ranging from 38% in Thailand to 72% in Cambodia and Lao PDR (Figure 4.2).

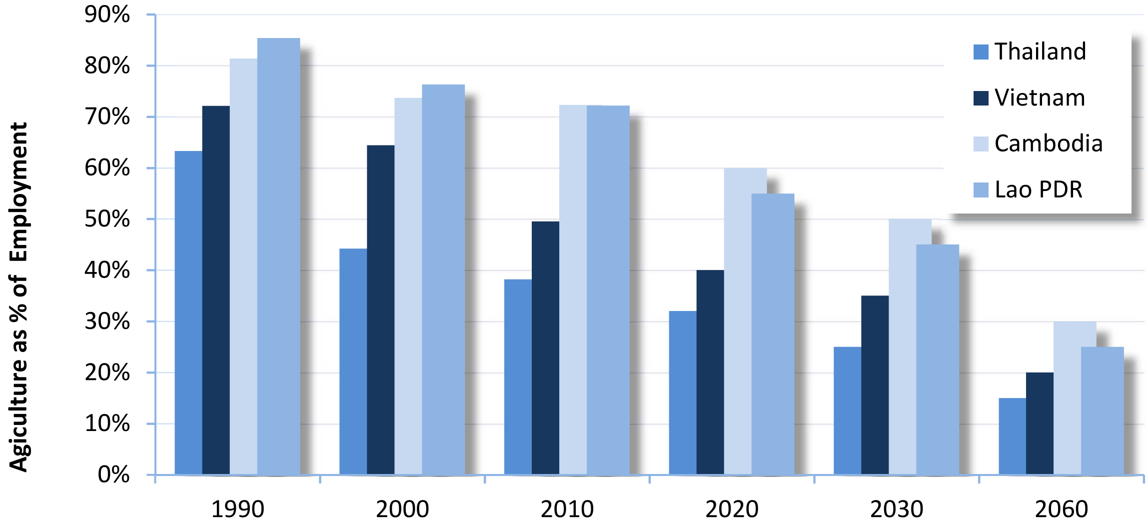


Figure 4.2: Contribution of agricultural sector as % of employment in LMB countries (MRC, 2016a).

The agricultural sector's contribution to employment has therefore not fully reflected the structural transformation in LMB economies and a large proportion of the population will continue to be dependent on agriculture and fisheries livelihoods. It is expected the relative contribution of agriculture to livelihoods and employment will continue to decline in the long term (Figure 4.2).

Between 1990 and 2010 rice production more than doubled from 40.4 to 86.4 million tonnes (Table 4.1). The area of maize in LMB countries totalled 2.83 million ha in 2010, of which Thailand and Viet Nam were the main producers. Since 1995 the area of maize has fallen in Thailand, but has increased in Viet Nam, Cambodia and Lao PDR. The main cash crops cultivated in LMB countries include sugarcane and rubber and in 2010 these crops accounted for 1.28 and 2.40 million ha, respectively.

Table 4.1: Rice production in LMB countries (tonnes per annum) (MRC, 2016a).

Country	1990	2000	2010
Thailand	17,193,410	25,843,727	35,584,134
Viet Nam	19,225,168	32,529,644	40,005,379
Cambodia	2,499,984	4,026,133	8,245,393
Lao PDR	1,491,463	2,201,704	2,583,186
Total	**40,410,025**	**64,601,208**	**86,418,092**

Sources: FAOSTAT, Crop Production, 2014

Irrigation is the largest water user in the LMB and the area under irrigation has gradually expanded in all four LMB countries during the past two decades (MRC, 2016a). All countries have prepared plans to expand irrigated areas to increase rice production, enhance food security and mitigate rural poverty. Various assessments of development scenarios for the LMB suggest that future flows in the Mekong mainstream will accommodate the planned expansion of irrigated areas.

The production of rice under irrigation in the LMB has significantly increased in recent years, and the Mekong Delta in Viet Nam is the largest rice producer in the Basin with more than 20 million tonnes per annum (Figure 4.3). In the irrigated region of Can Tho and Tra Vinh provinces of Viet Nam, farmers produce three rice crops per year (winter-spring, summer-autumn and autumn-winter) while, in Siem Reap and Battambang provinces of Cambodia, rice growers produce two rice crops per year (spring and autumn).

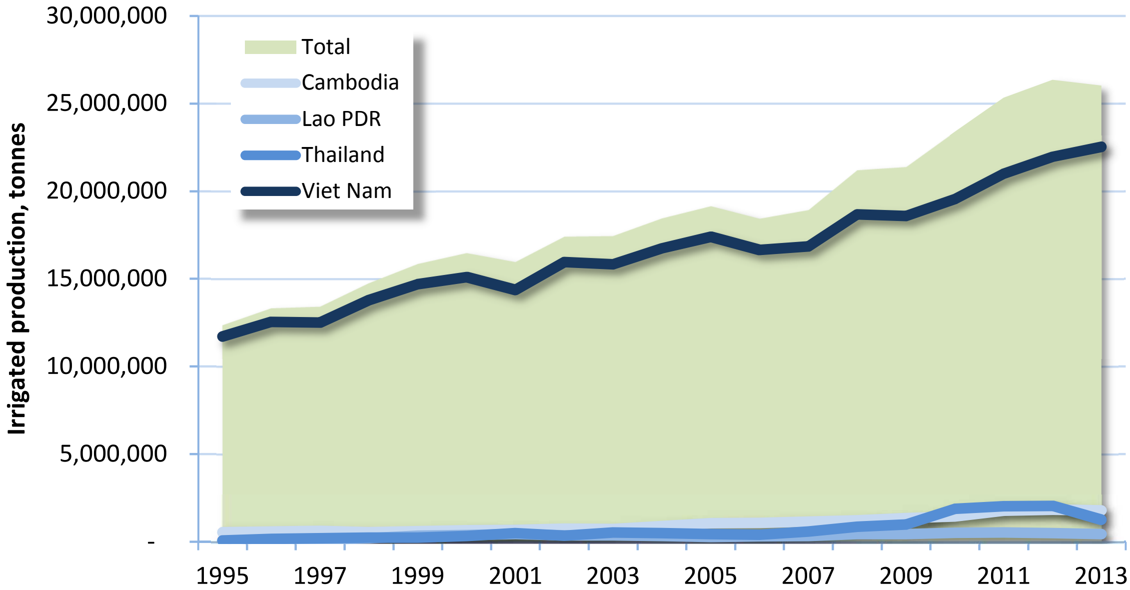


Figure 4.3: Past trends in irrigated rice production in the LMB (MRC, 2016a; *Source: data from member countries).*

Viet Nam and Thailand continue to be the world's largest exporters of rice. In 2011, Thailand exported about 10.7 million tonnes with Viet Nam providing an additional 7.1 million tonnes. Expanded irrigation areas and improved agronomic practices have also enabled Cambodia to export about 174,000 tonnes in 2011,with a target of one million by 2015, while Lao PDR is reported to have exported 2,200 tonnes in 2011 with a target of 600,000 tonnes by 2015 (FAOSTAT 2012; World Bank 2012).

An assessment of average net incomes from rain fed and irrigated cropping systems in the LMB indicated that with supplementary irrigation significantly increases the net income per hectare from wet season cropping. However, a recent study (MRC, 2014b) revealed a high degree of variability. The average net income from irrigated rice is greater than from rain fed rice, but some rain fed producers achieve higher net incomes than irrigated producers. The study also showed that average net returns from irrigated rice are higher that the net returns from cassava, soybean and maize.

Irrigated maize is only grown in Cambodia, and irrigated maize production in the LMB has increased in recent years to reach 74,000 tonnes in 2013 (Figure 4.4).

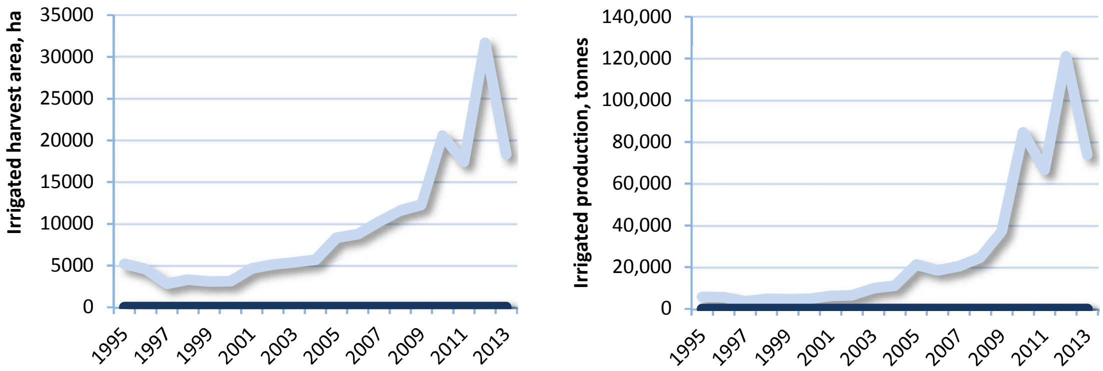


Figure 4.4: Past trends for irrigated maize harvest area and production in the LMB (MRC, 2016a).

Based on the farm gate prices of rice and maize in the respective LMB countries, the economic value (US$/annum) of irrigated rice in 2013 was estimated at US$ 6,482 million (Table 4.2) with maize contributing a further US$ 10 million. As the main producer of irrigated crops, Viet Nam accounts for 84 per cent of the total economic value. Other crops (including vegetables) are also grown under irrigation in LMB, but data were only available for irrigated rice and maize.

Table 4.2: Economic value of irrigated rice and maize in 2013 (US$/annum) (MRC, 2016a; *Source: *data from Member Countries, and **calculated from FAOSTAT*).

	Rice				Maize				Total
	Irrigated harvest area (Ha)*	Irrigated production (ton)*	Farm gate price (US$/ton)**	Economic value (US$/annum)	Irrigated harvest area (Ha)*	Irrigated productio n (ton)*	Farm gate price (US$/ton)**	Economic value (US$/annum)	Economic value (US$/annum)
Cambodia	410,419	1,796,631	268	480,719,060	18,358	73,974	138	10,208,417	490,927,477
Lao PDR	90,962	433,548	248	107,523,233	-	-		-	107,523,233
Thailand	356,514	1,254,402	244	305,793,825	-	-		-	305,793,825
Viet Nam	3,887,295	22,530,279	248	5,587,676,026	-	-		-	5,587,676,026
Total	4,745,190	26,014,861		6,481,712,143	18,358	73,974		10,208,417	6,491,920,560

The total area of rain fed rice in the LMB has gradually expanded over the past 20 years and was estimated at 8.4 million hectares in 2013. Thailand is the largest rain fed rice producer in the LMB with 5.6 million hectares followed by Cambodia with 2.2 million hectares.

The production of rice under rain fed conditions in the LMB is still very substantial, especially in Thailand and Cambodia, and totalled 22 million tonnes in 2013 (Figure 4.5) with Thailand and Cambodia accounting for 13 million tonnes and 6 million tonnes respectively. The area and production of rain fed maize have been increasing in Cambodia, Lao PDR, and Viet Nam, but have been decreasing in Thailand. In 2013, the overall area of rain fed maize in LMB was estimated at 0.92 million hectares with a total production of 4.4 million tonnes, of which 1.5 million tonnes was produced in Thailand (MRC, 2016b). The economic value (US$/annum) of rain-fed rice in 2013 was estimated at US$ 5,504 million (Table 4.3) with maize contributing a further US$ 607 million.

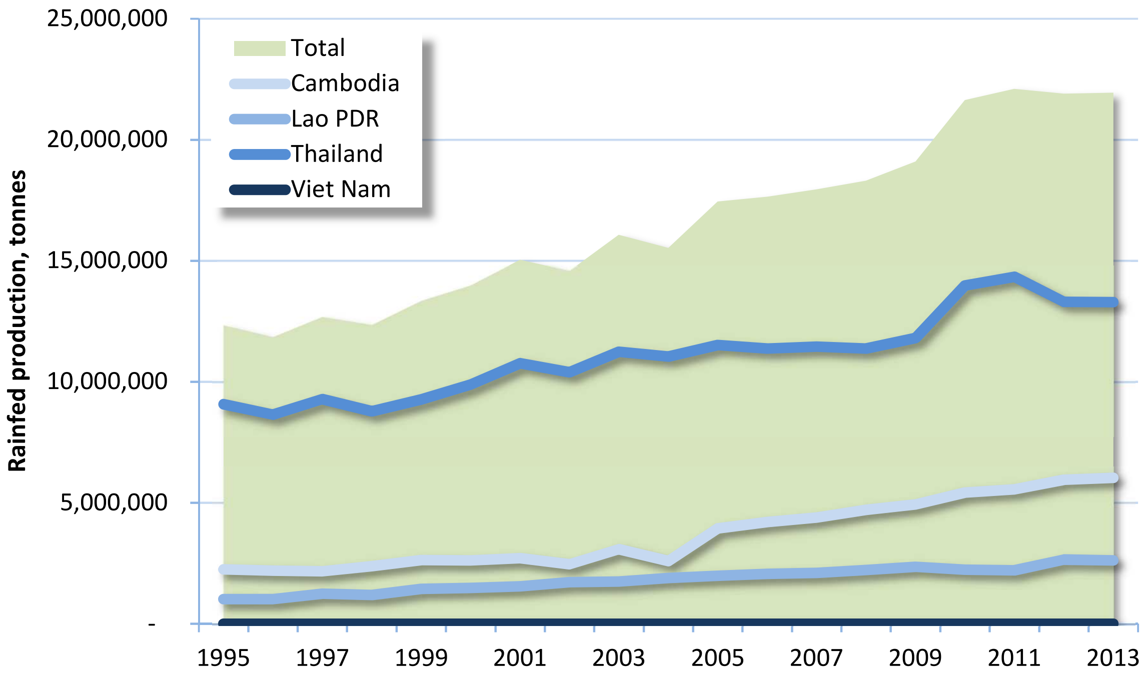


Figure 4.5: Past trends in rain fed rice production in the LMB (MRC, 2016a; *Source: data from Member Countries except Viet Nam).*

Table 4.3: Economic value of rain fed rice and maize in 2013(MRC, 2016a).

	Rice				Maize				Total
	Rainfed harvest area (Ha)	Rainfed production (ton)	Farm gate price (US$/ton)	Economic value (US$/annum)	Rainfed harvest area (Ha)*	Rainfed production (ton)*	Farm gate price (US$/ton)**	Economic value (US$/ annum)	Economic value (US$/annum)
Cambodia	2,062,004	6,030,854	268	1,613,657,301	189,121	824,553	138	113,788,578	1,727,445,879
Lao PDR	657,488	2,616,504	248	648,912,422	174,167	1,008,044	138	139,110,252	788,022,673
Thailand	5,640,349	13,298,185	244	3,241,785,806	364,881	1,544,398	138	213,127,334	3,454,913,140
Viet Nam	-	-		-	191,234	1,020,834	138	140,875,284	140,875,284
Total	**8,359,841**	**21,945,543**		**5,504,355,529**	**919,404**	**4,397,829**		**606,901,447**	**6,111,256,976**

4.1.2 Projected climate change impacts and vulnerabilities

No identified impacts on agriculture have been directly attributed to climate change to-date. However, the SIMVA 2014 survey (MRC, 2015f) identified that in Viet Nam's saline sub-zone, 23 per cent of the sample households reported impacts from salinity intrusion in the last 12 months. In terms of losses due to salinity intrusion, the average agricultural loss per household was US$276, and the average aquaculture loss was US$297. Agricultural losses over the preceding 12 months were also reported as a result of flooding (median US$375 of rice lost per household) and drought (US$454 per household).

USAID (2013) undertook crop modelling based on projected suitability of areas for crop production as a result of climate change. This showed that in several hotspot areas production of rain-fed rice and maize is expected to decline overall, mainly due to the vulnerability of plants to higher temperatures (Box 4.1). In only one area, in northeast Thailand, did production of rain-fed rice increase. The study did not consider changes in agricultural management practices that could have a significant impact on yields, for example, shifting the calendar for planting and harvesting dates, using early maturing varieties and increasing fertiliser use (USAID, 2013).

Box 4.1: Key findings on areas of projected crop suitability, from USAID (2013)

Rubber: *Projected increases in temperature and precipitation would open new upland areas for industrial rubber plantations cultivation. However, rubber plantations are projected to experience large negative shifts in production in Western Cambodia, the Vietnamese Central Highlands, and in recently planted areas like Champasak Province in Lao PDR due either to increased rainfall or prolonged drought.*

Robusta Coffee: *Changes in suitability for Robusta coffee are both positive and negative across the LMB but overall there will be a reduction in accessible areas suitable for the crop.*

Cassava: *At the basin level, change in rainfall and temperature will decrease the highly suitable area for cassava (52,000 km^2). Increased precipitation and extreme rainfall events with more floods will reduce yields in low-lying areas.*

Maize: *Increasing temperature and rainfall during planting, and erratic rainfall throughout the crop cycle will seriously affect production. By 2050, maize yield across the hotspot provinces will decrease by 3% to 12% due to increased rainfall or temperature.*

Soybean: *Cultivation will be negatively affected by increased rainfall and more extreme rainfall events before harvest. Also, increased temperatures will have a negative impact on yields.*

Lowland rain-fed Rice: *A yield drop of 3% to 12% is projected across the basin. Lowland rain-fed rice and irrigated rice will experience reduced yields due to temperatures higher than 35°C during the growing stage in the dry season.*

MRC (2013a) also simulated changes in yield for five crops under four RCPs and found that rice yields in most of the scenarios and sub-areas decreased. Maize yields increased slightly for some scenarios in some areas, while for sugar cane there was no general trend in yield and for cassava, only very minor impacts.

Mainuddin *et al.* (2010; 2011; 2012) found that yields of rain-fed rice and irrigated rice could increase significantly as a result of higher rainfall and increased CO_2 concentrations, notwithstanding the negative impacts of higher temperatures. Overall they found that rice and maize productivity are unlikely to be negatively impacted by the direct impacts (temperature and rainfall) of climate change. ICEM (2010) showed mixed results, while Eastham *et al*. (2008) found that any yield responses to projected climate changes are likely to be small.

Considering future development scenarios, MRC (2015g) project that a total of 133 million tonnes of rice could be produced by 2030 and a total of 161 million tonnes could be produced by 2060, with all LMB countries achieving substantial increases. It is also anticipated that the production of other food crops (i.e. maize, pulses and oil crops) will increase broadly in line with population growth (MRC, 2015g). With regard to export crops, the expansion in rubber and sugarcane production is likely to continue in the medium and long term in response to increasing global demand. However, future growth of upland export crops, as well as commercial forestry, will place increasing pressure on LMB catchments.

These increases in production are expected to be achieved through area expansion and higher productivity and it is anticipated that irrigation development will play an important role (Table 4.4). USAID (2013) also note, however, that both rain-fed and irrigated rice yields are vulnerable to high temperatures during the growing stage.

Table 4.4: Actual and planned irrigated areas in the Lower Mekong Basin (ha) (MRC, 2015g).

Country/Region	2010	2030	2060
N.E. Thailand	1,411,807	2,357,969	2,396,711
Viet Nam (Delta and Highland)	1,919,623	2,044,780	2,062,620
Cambodia	504,245	778,488	1,156,025
Lao PDR	166,476	451,296	717,485
Total	4,002,151	5,632,935	6,332,841

Increased temperatures will also affect soya, maize and cassava but their vulnerability is mostly due to the combined effects of increases in temperature and rainfall (USAID, 2013). Soya, rice, maize, and coffee are vulnerable to increased rainfall due both to waterlogging of lowland soils and also an increased incidence of pest and fungal diseases. Areas suitable for industrial crops (e.g. rubber, coffee and cassava) are expected to shift towards higher altitudes in Northern Thailand, Northern Lao PDR and the Central Highlands, while the plains (especially Eastern Cambodia) may become less suitable.

Increases in the frequency of extreme events such as floods and droughts will also have an impact on agricultural production. Drought can reduce yields or lead to the total loss of crops, especially rain-fed rice. Floods can destroy planted areas with lowland areas and especially the delta area where the impacts might be exacerbated by rising sea-levels, more at risk.

MRC (2017e) modelled the potential impacts of climate change on both rice and maize yields and projected that averaged over all scenarios, including irrigated and rain-fed production systems, impacts on yields are expected to be negative with larger impacts on rice than maize (Table 4.5). Data limitations, however, mean these results should be treated with caution (MRC, 2017e).

Table 4.5: Projected climate change impacts on rice yield across LMB countries in 2030 and 2060 (MRC, 2017e).

Crop type	Country	Baseline	2030		2060	
		Crop yield (ton/ha)	Crop yield (ton/ha)	% of change	Crop yield (ton/ha)	% of change
Rice	Cambodia	2.92	2.88	-1.45	2.83	-3.22
	Lao PDR	4.21	4.07	-3.51	3.99	-5.76
	Thailand	2.37	2.12	-11.42	2.06	-14.95
	Viet Nam	5.00	4.96	-0.97	4.92	-1.67
Maize	Cambodia	4.72	4.69	-0.79	4.67	-1.16
	Lao PDR	5.62	5.55	-1.33	5.54	-1.61
	Thailand	2.40	2.46	2.65	2.43	1.22
	Viet Nam	4.30	4.295	-0.13	4.295	-0.13

For rice production the most significant impacts are projected to occur up to 2030 with smaller decreases in yield between 2030 and 2060. For maize, the small decline in yield to 2030 is largely projected to continue to 2060 (Figure 4.6). The most significant impacts on rice yield are projected to be in Thailand and the most significant impacts on Maize in Lao PDR.

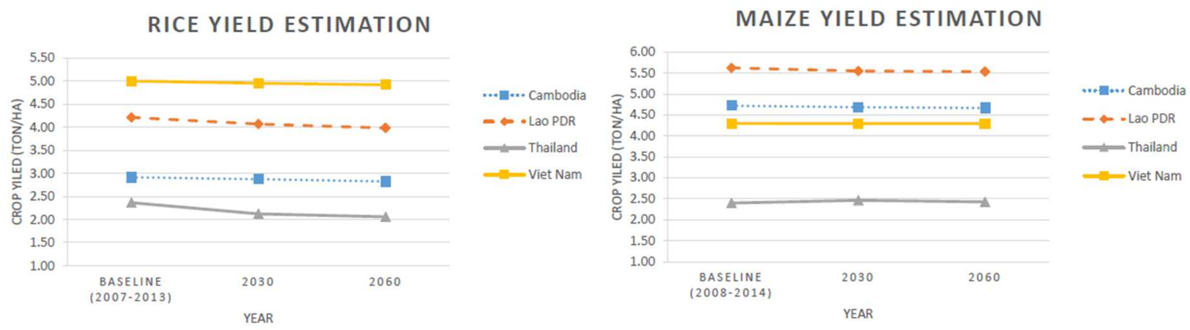


Figure 4.6: Projected trends in rice and maize yields across LMB countries due to the impacts of climate change (MRC, 2017e).

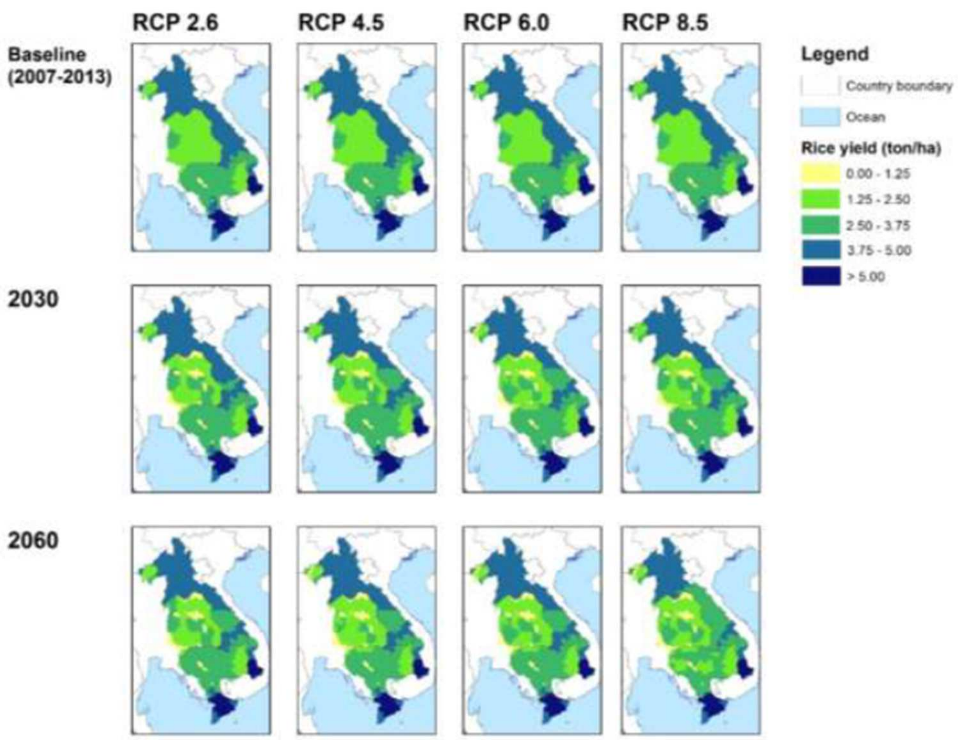


Figure 4.7: Projected climate change impacts on rice yield in the LMB (MRC, 2017e).

Livestock play an important role in many of the farming systems of LMB countries by providing a source of animal protein, cash income, draught power and manure, as well as financial security for subsistence farm households. The total cattle/buffalo population slowly increased from 21.6 million in 1990 to 23.7 million in 2010, despite a fall in cattle numbers in Thailand (MRC, 2015g).

Pig production has expanded in all LMB countries in recent years and the total number of pigs increased from 19.9 million in 1990 to 39.8 million in 2010. With increasing per capita incomes, the consumption of pig meat is likely to increase rapidly in the foreseeable future and it is estimated that the total pig population could reach 57 million by 2030 and almost 70 million by 2060.

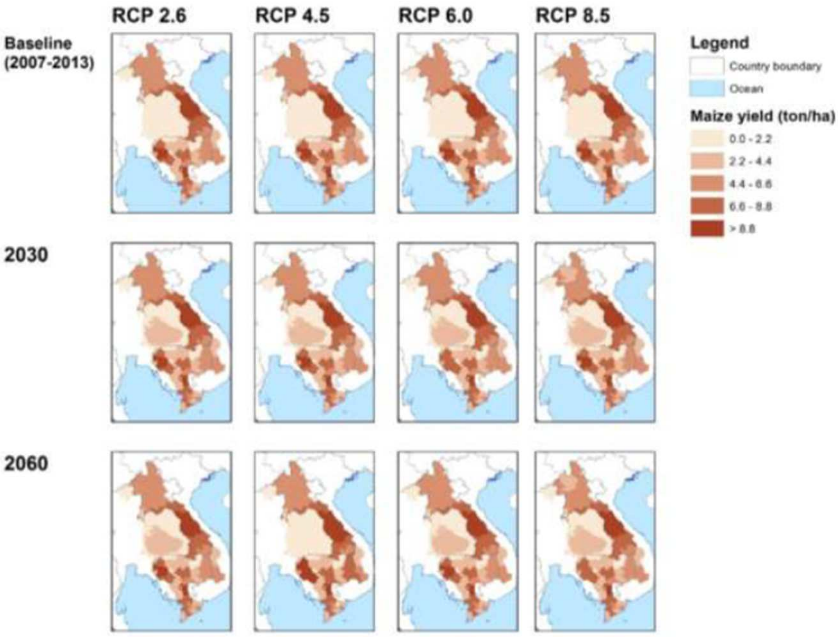


Figure 4.8: Projected climate change impacts on maize yield in the LMB (MRC, 2017e).

Poultry production has also substantially increased and the total number of poultry has risen from 253 million in 1990 to 600 million in 2010. The production of poultry meat and eggs is likely to continue to expand rapidly in response to domestic and export demand. It is estimated that the total poultry population could reach 836 million by 2030 and about 1.0 billion by 2060.

Despite increased farm mechanisation, it is projected that cattle/buffalo numbers will very gradually increase in the future in response to the domestic demand for milk and beef and, by 2030, will reach 26.1 million.

As identified in USAID (2013), livestock may be affected by climate change through several pathways. Individual animals in traditional systems will probably show only small measurable effects of higher temperatures but multiplied to a regional level the impacts may be significant. Temperatures above a threshold value for specific breeds will impact productivity and increase behavioural problems particularly in intensely stocked systems. Availability and price of local feed sources and ingredients will likely be affected by climate change, and this will mostly affect smallholders. Changes of feed availability caused by drought and flooding will negatively affect stock condition and resilience to disease. The quantity and quality of disease vector breeding sites as well as the likelihood of pathogen transmission through fomites will be changed. Current internal and external parasite problems may be exacerbated. In addition, the increased frequency and intensity of extreme events are likely to affect livestock negatively.

4.2 Fisheries and aquaculture

> ***Key findings***
>
> *Capture fisheries and aquaculture represent significant value to the economy of the Lower Mekong Basin. While overall yields are up, declines in catch per unit effort indicate a resource under pressure. Overall, Thailand is the most exposed to impacts on capture fisheries while Viet Nam is the most exposed to impacts on aquaculture. Projected impacts on fisheries could be positive or negative depending on the scenario, although with those dependent on flood zone habitats likely to experience greater changes than those in rice paddy habitats. Only minor impacts on aquaculture productivity are expected due to a significant number of provinces being unaffected by salinity intrusion.*

4.2.1 Past and current conditions

Thailand has the largest fish catch of LMB countries with 0.92 million tonnes, followed by Cambodia (0.77 million tonnes), Viet Nam (0.37 million tonnes) and Lao PDR (0.25 million tonnes) (MRC, 2015e). These overall production figures are higher than previous estimates, e.g. 1.5 million tonnes (MRC, 2003) and 1.9 million tonnes (MRC, 2010), but it is important to note that this does not mean there is an increase in capture fisheries production; the higher number can be attributed to the application of enhanced estimation methods.

With regard to past trends in capture fisheries production, MRC's long term monitoring of fish catches indicate that there are annual fluctuations, but no clear or significant trends in overall level of fish production. However, it should be emphasised that the number of fishers (using both legal and illegal fishing gear) has increased and more efficient fishing gear (e.g. gill nets) is also being adopted. The rate of fish catch or catch per unit effort (CPUE) has therefore been declining in recent years (MRC, 2015f).

Based on average first-sale prices in each of the four Member Countries, the economic value of the 2.3 million tonnes of annual capture fish production was calculated at about US$ 11.2 billion (Figure 4.6) with Thailand contributing US$ 6.4 billion, followed by Cambodia (US$ 2.8 billion), Lao PDR (US$ 1.3 billion), and Viet Nam (US$0.8 billion). Furthermore, capture fisheries accounts for 65% of the total value of fisheries production in the basin (including aquaculture) which is estimated at US$ 17.0 billion.

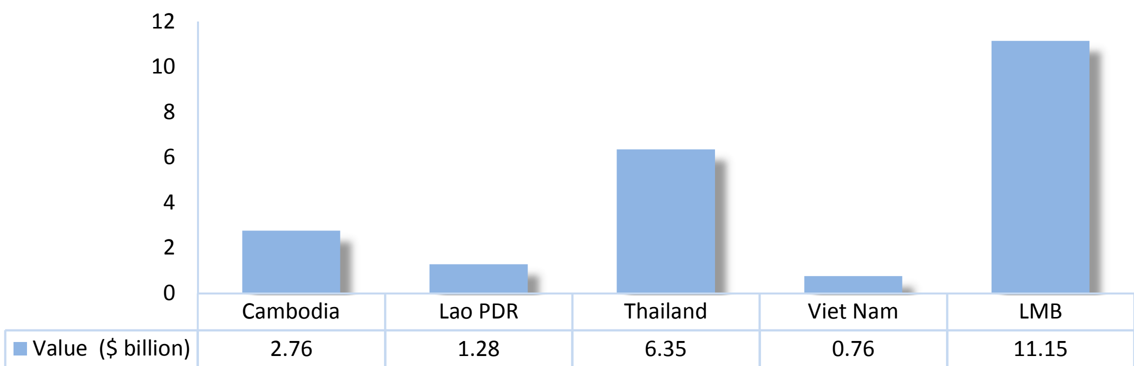


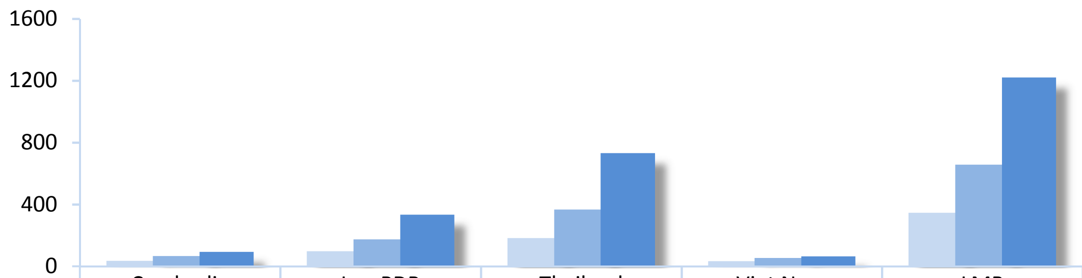
Figure 4.6: Economic value of capture fisheries in the LMB (US$ billion, 2015) (MRC, 2016a; *Source: MRC Fisheries Programme estimates from national fisheries statistics).*

The overall unit value of capture fisheries in LMB is derived from first-sale prices of wide variety of fish species (MRC, 2016a). The value of capture fish in Thailand is high with an average price of US$6.9/kg in 2015. In comparison, the average capture fish prices in Cambodia and Lao PDR were estimated at US$3.6/kg and US$ 5.2/kg respectively while, in Viet Nam, the average price was much lower at US$ 2.1/kg. In 2015, the overall unit value of capture fisheries in LMB was therefore estimated at US$ 4.85/kg.

It should, however, be noted that high value fish (e.g. white fish) are usually sold, whereas low value fish (e.g. black fish) are often consumed directly by fisher households. Using first-sale prices will therefore be biased towards higher value species and so over-value capture fisheries production in the LMB.

Reservoir fisheries are an important type of capture fisheries in the LMB and large water bodies (mainly reservoirs) are estimated to contribute about 10% of the annual capture fisheries yield (or 230,000 tonnes). Thailand accounts for about 50% of the yield from these water bodies and a further 25% comes from reservoirs in Lao PDR (Hortle and Bamrungrach, 2015).

Based on average first-sale fish prices in the Member Countries, the economic value of reservoir fisheries was estimated at US$ 1.22 billion, up from US$660 million in 2010 and about US$ 350 million in 2003 (Figure 4.7). Thailand accounted for 60% of the total economic value, while Lao PDR contributed a further 27%. The economic values of reservoir fisheries are significantly lower in Cambodia and Viet Nam.



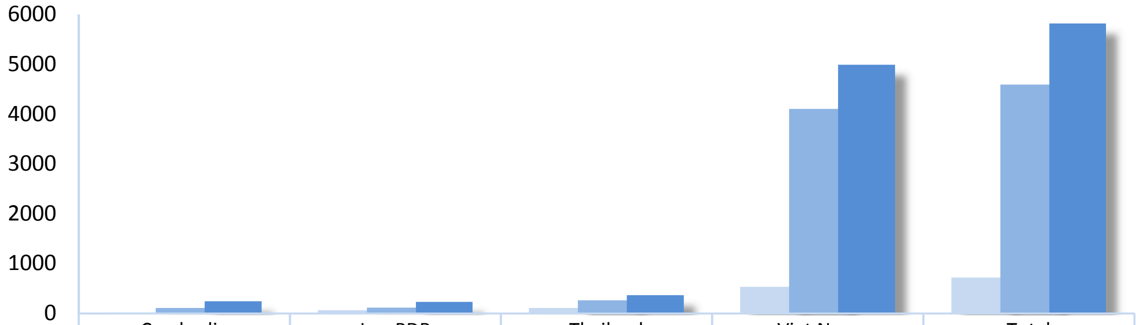
	Cambodia	Lao PDR	Thailand	Viet Nam	LMB
2003	33.8	96	182.9	33	345.7
2010	65	172.8	365.7	54	657.5
2015	93.6	332.8	731.4	63	1,220.80

Figure 4.7: Economic value of reservoir fisheries in the LMB (US$ million, 2015 prices) (MRC, 2016a; *Source: MRC Fisheries Programme estimates from national fisheries statistics*).

Aquaculture production has been growing rapidly in the LMB and reached 2.1 million tonnes in 2012, up from 1.8 million tons in 2010 and about 0.7 million tonnes in 2002. The average annual growth rate has been around 17%, which is three times faster than the world average of 5.6% in the decade up to 2014 (OECD/Food and Agriculture Organization, 2015). Viet Nam is by far the largest producer in the LMB with 1.8 million tons of fish produced in 2012. However, annual production growth in the Mekong Delta has now slowed down and fish exports, which are subject to market demand in Europe, USA and Japan, have not significantly increased in recent years.

Based on farm gate fish prices in the Member Countries, the economic value of aquaculture production in the LMB was estimated at US$ 5.8 billion in 2015, up from US$4.6 billion in 2010 and

US$0.7 billion in 2003 (Figure 4.8). Viet Nam is by far the largest producer, accounting for 86% of the basin’s production value, followed by Thailand (6%), Cambodia (4%) and Lao PDR (4%).



	Cambodia	Lao PDR	Thailand	Viet Nam	Total
2003	18.1	62	105.7	527.5	713.3
2010	109.2	114.9	260.6	4,102.50	4,587.20
2015	239.4	228.6	363.1	4,983.80	5,814.90

Figure 4.8: Economic value of aquaculture production in the LMB (US$ million in 2015 prices) (MRC, 2016a; *Source: MRC Fisheries Programme estimates from national fisheries statistics).*

4.2.2 Projected climate change impacts and vulnerabilities

No identified impacts on fisheries and aquaculture have been directly attributed to climate change to-date. However, the MRC’s SIMVA 2014 (MRC, 2015f) survey identified that in Viet Nam’s saline sub-zone, 23 per cent of the sample households reported impacts from salinity intrusion in the last 12 months. In terms of losses due to salinity intrusion, the average aquaculture loss was US$ 297.

MRC (2016f) identified that fish yields from different habitats may increase or decrease depending on the scenario although with flood zone habitats being impacted to a greater extent than paddy rice habitats. In terms of the cumulative yields from both habitats, small changes are expected in the short-term when development is absent from the scenarios; however, losses become much more significant in the short term when development impacts are also considered. Conversely, this tendency is not as strong when comparing scenarios in the medium term, out to 2060.

With regards to aquaculture, MRC (2016f) found that minor changes to current production levels could be expected as a result of severe salt intrusion in the Delta. More than 60 per cent of the current production takes place in four provinces (Dong Thap, An Giang, Can Tho, and Vinh Long) that do not experience acute salinity intrusion and according to this assessment, are therefore not likely to experience acute salt intrusion in the short to medium term. On the contrary, significant losses are expected in Ca Mau Province, most of which will become virtually unfeasible for freshwater aquaculture by 2060.

4.3 Hydropower

No significant impacts on energy including hydropower production have been directly attributed to climate change to-date. Impacts on production depend on the direction of future changes, particularly river flow at different times of year. These impacts could be positive or negative both on the Mekong mainstream and in the tributaries with the drier overall model and the higher emissions scenarios having the biggest deleterious impacts on power production. The range in potential future impacts is considerable.

4.3.1 Past and current conditions

Hydropower is an important renewable energy resource in the Mekong Basin and the region has considerable potential for hydro-electric development at all scales, from large multi-purpose projects to feed national power grids to micro-scale projects for rural electrification. Government policies promote hydro-power production, not only for national requirements, but also to expand mutually beneficial cross-border power trade which will enhance regional economic integration and energy security. 59 hydroelectric power projects (out of a total of 140 projects) have been developed or are under construction. This represents 35% (10,017 MW) of the total 28,543 MW of hydro-electric potential in the LMB (Table 4.5) (as of 2014).

In addition, China recently completed its sixth large dam on the Lancang–Mekong in Yunnan province and the Yunnan cascade in Yunnan now comprises about 15,200 MW of installed capacity. This represents an electrical supply to about 75 million people (at current average per capita electricity use in the Greater Mekong Sub-region of 920 kWh/head/year).

Table 4.5: Current status of hydropower development in the LMB (MRC, 2016a; *Source: MRC hydro-power database, 2014).*

Status	E: Existing		C: Under construction		L: Licensed		PP: Planned (Level 1)		PH: Planned (Level 2)		**Totals**		
Country	Mainstream	Tributary	Mainstream	Tributary	Mainstream	Tributary	Mainstream	Tributary	Mainstream	Tributary	Mainstream	Tributary	All projects
Number of projects													
Cambodia		1				1	1	1	1	9	2	12	14
Lao PDR		18	1	18	3	22	4	15		21	8	94	102
Lao - Thai					1				1		2	0	2
Thailand		7									0	7	7
Viet Nam		12		2				1			0	15	15
Total	0	38	1	20	4	23	5	17	2	30	12	128	140
Installed capacity, MW													
Cambodia		1				400	2,600	100	978	729	3,578	1,230	4,808
Lao PDR		2,950	1,285	2,430	1,812	3,400	4,564	1,169		976	7,661	10,925	18,586
Lao - Thai					660				1,079		1,739	0	1,739
Thailand		745									0	745	745
Viet Nam		2,293		314				58			0	2,665	2,665
Total	0	5,989	1,285	2,744	2,472	3,800	7,164	1,327	2,057	1,705	12,978	15,565	28,543

Regional installed capacity is given in (Table 4.6) and it can be seen that installed capacity has rapidly expanded in recent years in all LMB countries. For example, in Viet Nam, capacity increased from 9,255 MW in 2005 to 31,495 MW in 2015, while in Lao PDR, capacity rose from 291 MW to 1,500 MW. Baseline production in the LMB averages 1132 MW which has a value of around $730m per year.

Table 4.6: Regional installed capacity (MW) (*MRC, 2016a; Sources: [1] Cambodia: PDP 2012; [2] Lao PDR: Electricité du Laos (2011 and 2013); [3] Thailand: EPPO, Ministry of Energy and EGAT; [4] Viet Nam: Viet Nam Ministry of Industry and Trade*).

Year	2005	2010	2015	2020	2030
Cambodia[1]	302	407	699	1,600	2,700
Lao PDR[2]	291	583	1,500	2,600	5,624
Thailand[3]	20,538	25,612	33,897	44,695	
Viet Nam[4]	9,255	20,000	31,495	50,000	68,440

The value of the energy produced by Mekong based hydropower may be derived from the "willingness to pay" (WTP) method contained in MRC (2015h) allowing for transmission costs. The Economic Price used to derive the gross economic value of Mekong based hydropower is shown in Table 4.7.

Table 4.7: Economic price for Mekong based hydropower production (MRC, 2016a).

	Net WTP (USD/kWh)	Financial Price (USD/kWh)	Economic Price (USD/kWh)
Cambodia	0.085	0.095	0.095
Lao PDR	0.041	0.065	0.065
Thailand	0.066	0.040	0.066
Viet Nam	0.053	0.045	0.053

Based on the Table 4.6 and 4.7 the following Gross Economic Value may be derived as shown in Table 4.8. Note that the evaluation of project portfolios should consider the Net Economic Value of these projects where the wider economic costs and benefits of the infrastructure are taken into consideration (MRC, 2015h).

Table 4.8: Gross economic value of Mekong based hydropower production in US$ million/year (MRC, 2016a).

Year	Cambodia	Lao PDR	Thailand	Viet Nam	Total
2005	0	208	58	281	**547**
2015	189	1,076	58	688	**2,011**
2020	189	2,963	58	698	**3,908**
2040	1,215	6,781	58	698	**8,752**

4.3.2 Projected climate change impacts and vulnerabilities

No existing impacts on hydroelectric power have been directly attributed to climate change to-date. Talberth and Reytar (2014) identify 11 major hydroelectric power facilities within the Lower Mekong Basin that are at risk from climate change. This assessment was based on identifying areas where temperature increases are expected to be the most significant and where agricultural drought months were expected to increase. The value of annual power production at risk from these facilities was calculated to be between US$294 to US$575 million. This estimate did not include the many small scale facilities for which data wasn't available, or the facilities at risk from extreme flooding basin-wide. Total values at risk may therefore be much higher.

The MRC's basin-wide climate change impact assessment on hydropower (MRC, 2017f) identifies that the impact on hydropower production depends significantly in whether the future is wetter or drier (Figure 4.9). Under the wetter overall model all countries are projected to experience an increase in energy production due to climate change with Cambodia having the largest increase to 2030 and Viet Nam the largest increase to 2060, under a medium emissions scenario (RCP4.5). Under the drier overall model, all countries except Viet Nam are projected to have lower energy production due to climate change, both to 2030 and to 2060, than they otherwise would (Figures 4.9 and 4.10.

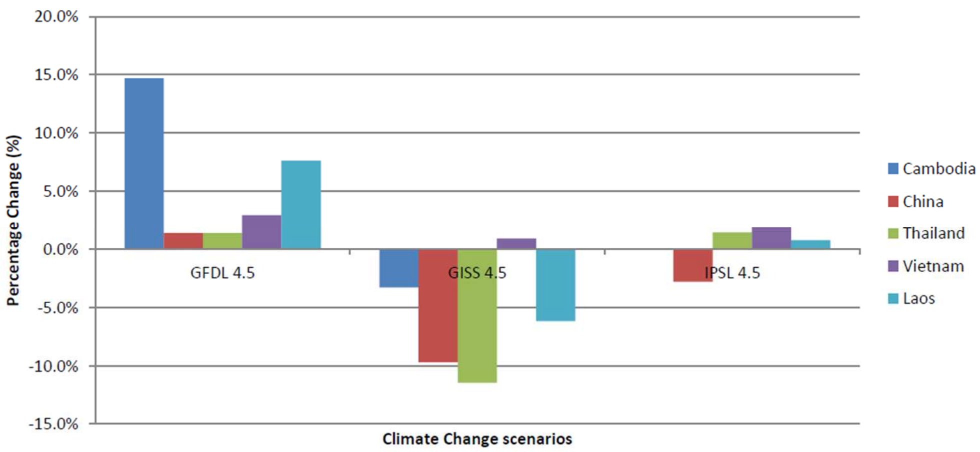


Figure 4.9: Percentage change in energy production under 2030 proposed dams under RCP4.5 scenario for the wetter overall (GFDL), drier overall (GISS) and increased seasonality (IPSL) models (MRC, 2017f).

The largest reductions in power production to climate change are projected to occur with the high emissions scenario (RCP8.5) under the drier overall model and this is worse in China and Thailand than elsewhere (-40%; Table 4.9), although Lao PDR is also badly affected (-30%; Table 4.9). The increased seasonality model also generally projects a reduction in power production under all emissions scenarios and for all countries although the impact is not as pronounced as for the drier overall model.

Overall the impact of climate change could be either negative or positive and is likely to affect power production in both the tributaries and the mainstream (Table 4.10). The range in potential future impacts is considerable. For example, in Thailand tributaries the change in minimum power production in the high emissions scenario to 2060 could be between -100 per cent under the drier overall scenario and +80 per cent under the increased seasonality model.

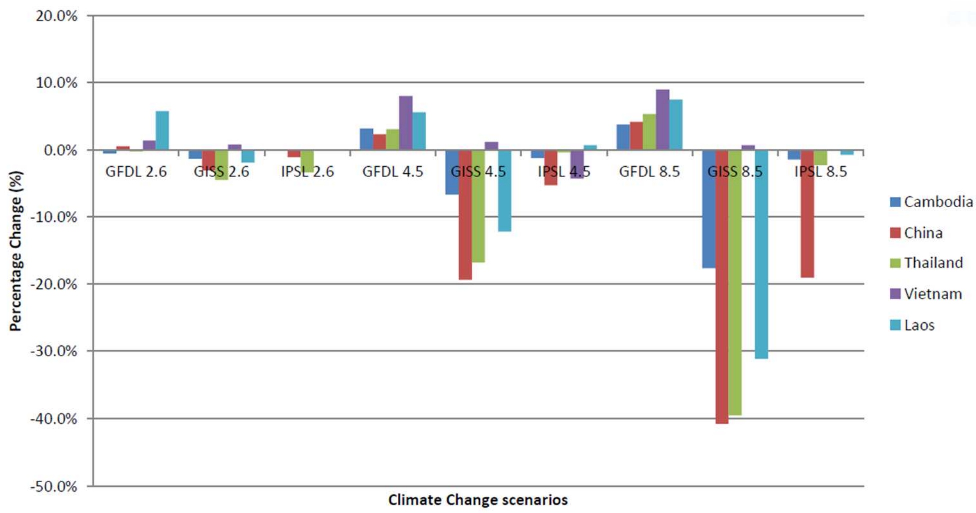


Figure 4.9: Percentage change in energy production under 2060 proposed dams under each emissions scenario for the wetter overall (GFDL), drier overall (GISS) and increased seasonality (IPSL) models (MRC, 2017f).

Table 4.9: Average change in power production with 2060 proposed dams compared to the 2007 climate baseline for each emissions scenario and the wetter overall (GFDL), drier overall (GISS) and increased seasonality (IPSL) models (MRC, 2017f).

	Wetter RCP2.6	Drier RCP2.6	Seasonal RCP2.6	Wetter RCP4.5	Drier RCP4.5	Seasonal RCP4.5	Wetter RCP8.5	Drier RCP8.5	Seasonal RCP8.5
Cambodia	-0.5%	-1.3%	-0.1%	3.2%	-6.7%	-1.2%	3.8%	-17.7%	-1.5%
China	0.5%	-3.0%	-1.1%	2.3%	-19.4%	-5.3%	4.2%	-40.8%	-19.1%
Thailand	-0.2%	-4.5%	-3.3%	3.1%	-16.8%	-0.4%	5.3%	-39.5%	-2.2%
Vietnam	1.4%	0.8%	0.0%	8.0%	1.2%	-4.2%	9.0%	0.7%	-0.1%
Laos	5.8%	-1.9%	0.0%	5.6%	-12.1%	0.7%	7.5%	-31.1%	-0.7%

Table 4.10: Percentage change in minimum daily power production with 2060 proposed mainstream and tributary dams compared to the 2007 climate baseline for each emissions scenario and the wetter overall (GFDL), drier overall (GISS) and increased seasonality (IPSL) models (MRC, 2017f)

	GFDL 2.6	GISS 2.6	IPSL 2.6	GFDL 4.5	GISS 4.5	IPSL 4.5	GFDL 8.5	GISS 8.5	IPSL 8.5
Cambodia (Main)	-5.66%	-3.45%	2.80%	8.82%	-27.71%	-1.15%	14.58%	-58.70%	-6.60%
Cambodia (Trib)	7.21%	4.32%	-0.35%	54.27%	0.53%	-49.26%	54.89%	-3.49%	-2.94%
China (Main)	1.30%	-30.50%	-0.76%	7.28%	-51.89%	-3.61%	28.94%	-60.54%	-32.01%
Thailand -(Trib)	0.58%	-0.16%	11.48%	29.93%	-88.98%	44.45%	58.94%	-100.00%	79.81%
Vietnam (Trib)	26.81%	17.76%	-2.45%	105.30%	4.24%	-98.77%	102.97%	4.74%	-0.46%
Laos (Main)	-1.02%	-2.35%	0.88%	7.12%	-39.13%	-0.84%	21.70%	-66.01%	-38.08%
Laos (Trib)	4.10%	-5.70%	-0.22%	17.63%	-25.72%	6.87%	23.85%	-46.10%	12.42%

4.4 Navigation and infrastructure

No significant impacts on navigation or infrastructure have been attributed to climate change to-date. Future impacts could result from changes in water levels, particularly in the narrow and turbulent upper reaches of the Mekong River during the dry season. Significant drops in water level may make passage impossible through particular reaches for certain periods of the year.

The availability of water supply, sanitation and energy infrastructure has been rising across the LMB with more and more people having improved access. It is anticipated that climate change will impact on roads and water supply infrastructure due to more intense rainfall, flooding and landslides. Significant expenditure may be required to protect coastal infrastructure from rising sea levels and storm surges.

4.4.1 Past and current conditions

The Mekong River is an important inland waterway for the transport of people and cargo between numerous communities situated along the river. In addition to providing these traditional links, the river is also a vital international trade route connecting the six Mekong countries to each other as well as the rest of the world. On average, per unit costs of Inland Waterway Transport (IWT) are higher than road transport. However, for larger volumes of cargo being transported over long distances, IWT has a cost advantage.

During the past decade, the volumes of cargo transported by inland waterways increased significantly and this growth provides a solid basis for the future development of IWT. With improvements in waterway capacity, as well as port facilities and vessel efficiency, it is expected that the IWT will continue to play a key role in the integrated regional transport network.

In the upper reaches of the Mekong, narrow and turbulent sections of the river (above the Khone Falls), together with the large seasonal variations in water levels, are key constraints to the growth of shipping with cargo volumes decreasing by more than 50% during the low water season (January–June).

In total there are approximately 40 places between the Golden Triangle and Kompong Cham, where the Least Available Depth (LAD) during the dry season is less than 2.0 m. Between Kompong Cham and Phnom Penh there are some four places where the LAD is less than 6.0 m and downstream Phnom Penhto Cai Mep, there are some six places where the LAD is less than 8.0 m (MRC, 2015i). Nevertheless, the Mekong River provides an important link in the transit route between Kunming and Bangkok. Overall, it is estimated that about 800,000 tonnes of IWT cargo are being shipped annually between China, Thailand, Myanmar and Lao PDR.

Forecast IWT cargo and passenger flow is expected to grow exponentially to 2040 both between China, Thailand, Myanmar and Lao PDR and between Cambodia and Viet Nam (MRC, 2016a).

Infrastructure improvements are assessed in consideration of the access to improved sanitation facilities, improved water sources, electricity and the proportion of paved roads and telephone lines. Access to improved sanitation facilities refers to the percentage of the population using facilities including flush/pour flush (to piped sewer system, septic tank, and pit latrine), ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilets. The percentage of the population with access to improved sanitation facilities seen in **Error! Reference source not found.** indicates that there were more than 90% in Thailand. In Viet Nam, Lao PDR and Cambodia access is gradually increasing and by 2012 had reached 60-65%, 40-50% and 20-30%, respectively.

A high rate of using improved sanitation facilities helps reduce the risk of digestive disease due to *E. coli* outbreaks from natural water sources. The World Health Organisation (WHO) reported country statistical profile on health that the distribution of causes of deaths of children under 5 by Diarrhoea in 2013 is 3%, 8%, 11% and 12% in Thailand, Cambodia, Lao PDR and Viet Nam respectively. The numbers listed in the report corresponded well to the percentage of population with access to improved sanitation facilities in Thailand, Cambodia and Lao PDR.

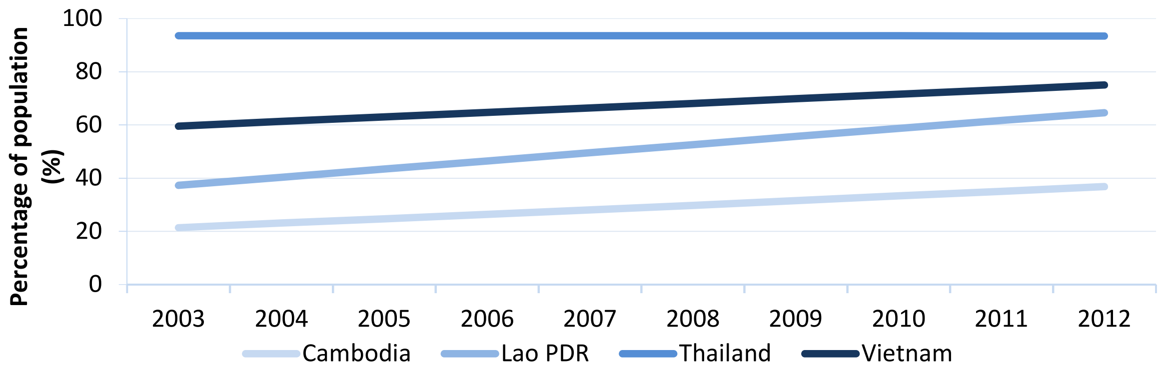


Figure 4.9: Percentage of population with access to improved sanitation facilities (MRC, 2016a; *Source: World Bank http://data.worldbank.org/indicator).*

Access to an improved water source refers to the percentage of the population using an improved drinking water source. The improved drinking water source includes piped water on premises (piped household water connection located inside the user's dwelling, plot or yard), and other improved drinking water sources (public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, and rainwater collection).

As illustrated in Figure 4.10, the percentage of population access to an improved water source gradually increased year by year over the last ten years, particularly in Cambodia, Lao PDR and Viet Nam, which were 40-50%, 60-70% and 80-90%, respectively. In Thailand, 99% of the population already has had access to an improved water source since 2014.

Despite improvements in drinking water sources in the LMB Corridor, river water is still used for drinking water, especially in Cambodia and Lao PDR, with a mean percentage of 82% and 55% respectively of village households using river water as one of several drinking water sources (MRC, 2016a).

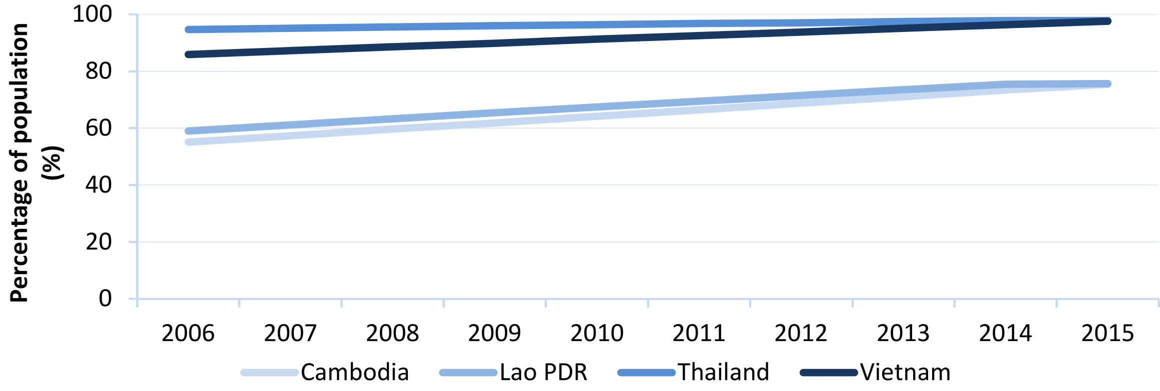


Figure 4.10: Percentage of population with access to an improved water source (MRC, 2016a; Source: World Bank http://data.worldbank.org/indicator).

Access to electricity is indicator of access to basic infrastructure invested by government. Almost the entire populations in Thailand and Viet Nam have access to electricity (Figure 4.11). In contrast, in Cambodia, 30% of the population had access to electricity in 2012, up from 20% in 1990. Access in Lao PDR is similarly increasing and had reached 70% by 2012.

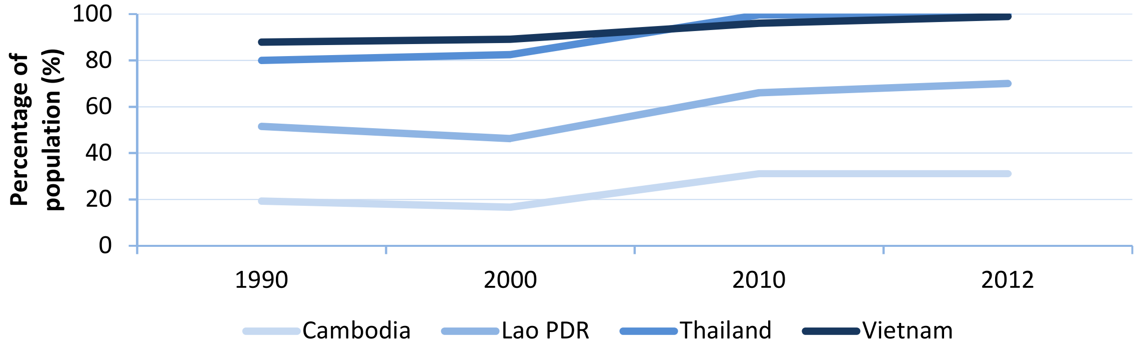


Figure 4.11: Percentage of population with access to electricity (MRC, 2016a; *Source: World Bank http://data.worldbank.org/indicator*).

Regional variations in access to safe drinking water, sanitation and grid electricity are illustrated in Figure 4.12. Higher rates of all three are evident in provinces of Thailand and Viet Nam than in Cambodia and Lao PDR.

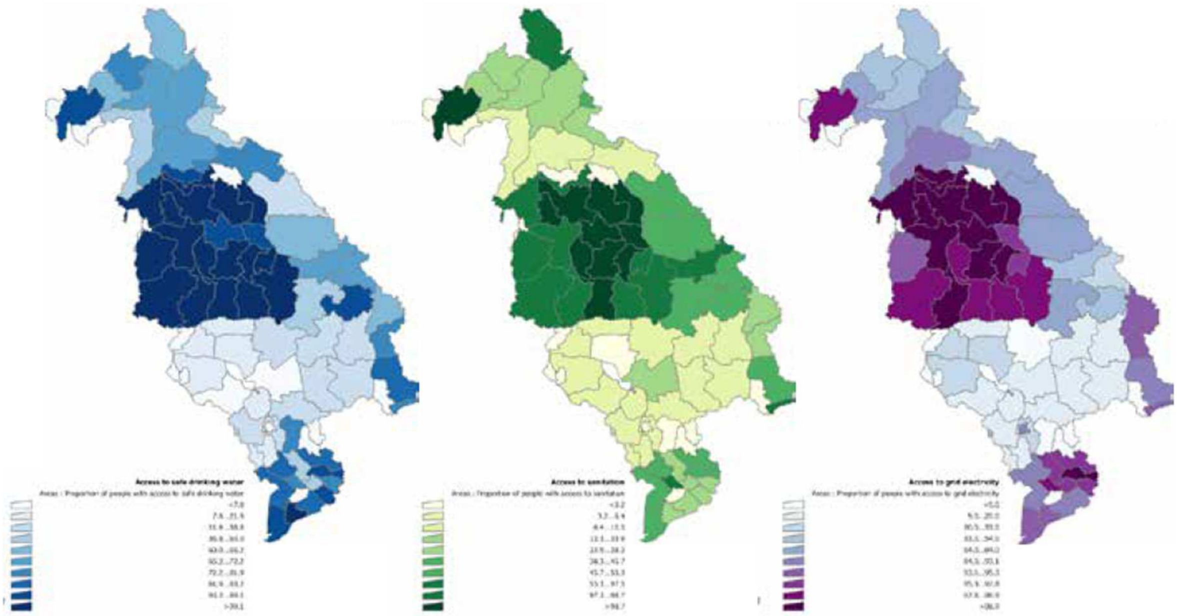


Figure 4.12: Access to safe drinking water, sanitation and grid electricity (MRC, 2015f).

The proportion of paved roads and phone lines has been rising in Thailand and Viet Nam, but remains relatively flat in Cambodia and Lao PDR (Figure 4.13). This may be because the overall quantity of roads is increasing faster than the quantity of paved roads in those countries; and due to recent advances in mobile telephony rather than fixed phone lines.

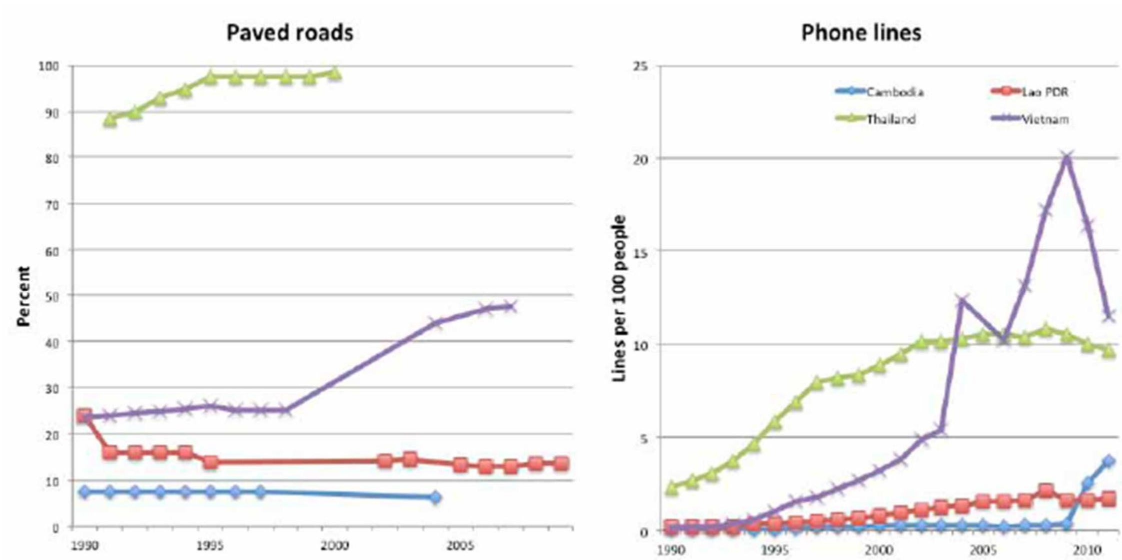


Figure 4.13: (a) Proportion of roads that are paved in each LMB country; and (b) the number of phone lines per 100 people in each LMB country (USAID, 2013).

4.4.2 Projected climate change impacts and vulnerabilities

To-date no impacts on navigation or infrastructure have been directly attributed to long-term climate change. However, if the change that occurs is closer to the drier overall scenario than the wetter overall scenario, future impacts on navigation could be significant. As identified in Section 3.1 annual river levels could drop by as much as 1.69 metres at Chiang Saen and 1.92 metres at Kratie. Given the number of places where the least available depth is less than 2 metres (MRC, 2015i), this could make many points in the river impassable for some traffic at certain times of the year.

USAID (2013) identified two key areas of the rural infrastructure sector that are highly vulnerable to climate change: roads and water supply infrastructure. The most prominent threats are considered to be flooding, flash flooding and landslides. Roads are critical infrastructure and highly exposed in both upland and lowland regions; a conclusion supported by Chaudhry and Ruysschaert (2007). Many roads are unsealed and structurally unstable, particularly in the uplands which makes them highly susceptible to damage from flash floods. In lowland areas the proximity of roads to rivers and lakes makes them susceptible to floods (USAID, 2013).

USAID (2013) found that water supply infrastructure is susceptible to degradation and contamination by prolonged flooding, destruction by sudden violent events such as landslides and inundation by sea level rise and storm surges. Damage to irrigation infrastructure would be expected to have prolonged and far reaching impacts (USAID, 2013).

Regmi and Hanaoka (2011), ADB (2011) and ADB (2013) identify the risks to infrastructure from climate change including:

- Sea level rise and storm surge increasing the risk to coastal infrastructure including energy systems leading to power outages, as well as flooding of roads and transport facilities in low-lying areas
- More intense rainfall increasing the risk of flooding, erosion, landslides causing damage to road and other infrastructure
- More intense heat could impact on roads and rail tracks causing transport disruption
- Heavy rainfall, flooding and rising sea levels could put residential and commercial buildings at risk in some areas

Esteban *et al.* (2014) looked at the potential impacts of sea level rise on infrastructure in coastal areas of Viet Nam. Using the case study of the port of Phan Thiet they found that an increase in cross-section of the breakwater of +20% to +70% would be required, depending on the scenario, to protect the port from higher waves. Also examining the potential damage to infrastructure in the Delta, Chinowsky *et al.* (2012) estimate that a 1 metre rise in sea level would cause damages to roads with a cost of US$2 billion.

Nicholls *et al.* (2008) estimated the increase in annual exposure of economic assets to a 1 in 100 year surge-induced flood event for 136 port cities around the world. While none of those were within the LMB, three are within LMB countries – Bangkok, Hai Phong and Ho Chi Miinh City. As reported in Talberth and Reytar (2014), the increase in exposed economic assets from a 2005 baseline year was estimated to be US$1,079 billion, US$323 billion, and US$626 billion, respectively.

4.5 Food security

> *No significant impacts on food security have been directly attributed to climate change to-date. Food security has increased significantly across all four LMB countries in recent decades with the prevalence of under-nourishment declining dramatically and the adequacy of dietary energy and average dietary protein both increasing. Nevertheless, given the importance of natural systems to rural livelihoods and the likely impact of climate change on natural ecosystems, many populations particularly in rural areas are likely to be vulnerable. Projected declines in rice and maize yields may negatively impact food security if not offset by increased production, given the importance of these crops for overall energy intake.*

4.5.1 Past and current conditions

Thailand and Viet Nam are major exporters of food, particularly rice. In contrast, even though Cambodia has begun to export rice, both Cambodia and Lao PDR are net food importers. Nevertheless, in overall terms, LMB countries generate substantial and increasing food surpluses for export worldwide. The issue of food security should therefore be focused on the adequacy of household diets and prevalence of under-nourishment among households within the LMB countries rather than national food self-sufficiency (MRC, 2016a).

There was a notable improvement in the adequacy of dietary energy between 1990 and 2010. In Thailand, dietary energy as a proportion of dietary requirement rose from 90% to 118%. Similar increases in dietary energy were achieved in Viet Nam, Cambodia and Lao PDR. There have also been significant improvements in average dietary protein. Between 1990 and 2010, dietary protein in Viet Nam increased from 45 to 75 gram/capita/day. Similar increases were recorded in Cambodia and Lao PDR, but were lower in Thailand (Table 4.9). However, levels of dietary protein are still well below the levels in Northern Europe.

In addition, table 4.9 shows that there has been a marked decline in under-nourishment in all LMB countries. For example, in Thailand, the proportion of the population classified as under-nourished decreased from 43% in 1990 to 12% in 2010. Similar falls were also evident in Viet Nam (48% to 21%), Cambodia (39% to 13%) and Lao PDR (41% to 22%). It should, however, be noted that these average figures do not show the level of food security experienced by poorer, more vulnerable groups within the population.

The influence of improved agricultural production and economic development more generally are also visible in rapid declines in the Global Hunger Index (GHI) for LMB countries (Table 4.10). This composite index incorporates measures of the incidence of under-nourishment in the population as a whole, infant malnutrition, and infant mortality. Despite considerable improvement, table 4.10 nevertheless indicates that food security remains a problem in all of the LMB countries.

With expanding food exports to meet global demand, LMB countries will continue to maintain overall food sufficiency at the national level in the medium and long term. Continued focus will still be needed, well into the future, on the food security of vulnerable households and on reducing malnutrition, especially in Lao PDR and Cambodia. Small scale agriculture, agricultural labour, low skilled manufacturing, and capture fisheries are expected to remain important sources of food and income for vulnerable households. It is expected that, by 2030, the prevalence of under-nourishment will be reduce to less than 5% of the population of the LMB countries.

Table 4.9: Food Security in LMB Countries *(*MRC, 2016a; *Source: FAOSTAT, Food Security Indicators, 2014).*

Country	1990	2000	2010
Adequacy of Dietary Energy (dietary energy supply as % dietary requirements)			
Cambodia	94%	100%	107%
Lao PDR	92%	96%	102%
Thailand	90%	110%	118%
Viet Nam	89%	106%	117%
Average Dietary Protein (gram/capita/day) Northern Europe = 105			
Cambodia	45	54	62
Lao PDR	49	58	65
Thailand	53	62	62
Viet Nam	45	59	75
Prevalence of under-nourishment (% of population)			
Cambodia	39.4%	19.8%	12.8%
Lao PDR	41.2%	36.7%	22.2%
Thailand	43.3%	18.0%	11.8%
Viet Nam	48.3%	32.3%	20.8%
Value of food imports as % total value of exported goods			
Cambodia	10%	6%	9%
Lao PDR	10%	13%	11%
Thailand	2%	2%	2%
Viet Nam	5%	4%	6%

Table 4.10: Global Hunger index for LMB Countries (MRC, 2016a; *Source: IFPRS 2013).*

Country	**1990** *(Data from 1988-92)*	**1996** *(Data from 1994-98)*	**2001** *(Data from 1999-2003)*	**2012** *(Data from 2005-2010)*
Cambodia	31.8	31.5	26	19.6
Lao PDR	28.6	25.2	23.6	19.7
Thailand	15.1	11.8	9.2	8.1
Viet Nam	25.6	21.4	15.5	11.2

Aggregate data like this can obscure important differences among different groups within the population. Different communities undertaking different livelihoods can be more or less exposed to shocks than others in different sectors. Within the LMB, natural systems are often critical to the food security of rural and remote communities, with non-timber forest products and protected areas playing an important food security safety net. USAID (2013) identified that 98% of the total sample population from a WFP study in Lao PDR (WFP, 2007) were all between 40% and 60% dependent upon some combination of subsistence farming, fishing/hunting and gathering. All sectors which depend on healthy ecosystems. USAID (2013) also suggest that a decrease in average rice yields of just a few per cent per hectare would have a dramatic impact on LMB food security and food production.

4.5.2 Projected climate change impacts and vulnerabilities

FAO defines the multi-dimensional issue of food security as existing when “all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life”. Food security rests on the four dimensions of: (i) food availability; (ii) food accessibility; (iii) food utilization; and (iv) food systems stability (FAO, 2008).

In considering the potential impacts of climate change on food security in the Lower Mekong Basin, MRC (2017e) focused on the food nutrient balance (food utilization) and the provision of sufficient, adequate and nutritious food to the population (food availability) under different climate change scenarios. While the projected impacts of climate change on food security were not modelled directly, evaluating the three main aspects of the nutrient balance: (i) total energy in kcal/day, (ii) protein in g/day, and (iii) total fat in g/day and using Food Balance Sheets for several nations and specific years as published by the FAO it was observed for the LMB countries that in general terms the population receives about 90 per cent of the energy, about 60 to 70 per cent of the proteins and 55 to 60 per cent of the fats & oils from agricultural products (rice, maize, sugar, veg. oils, etc.).

As a result, projected climate change impacts on crop yields and in particular rice and maize are an important consideration for future food security (see Section 4.1). Simple linear projections based on improvements to date would indicate that rice and maize yields to 2030 may continue to improve across all Member Countries and animal production may increase in Lao PDR and Viet Nam but decrease in Cambodia and Thailand (MRC, 2017e). However, at present no general consensus has been reached on how climate change may affect the production of rice in the LMB. Clearly the impact will be different in different regions, and will depend on the dominant factors (positive and negative) affecting yield in each region (MRC, 2017e).

Twelve case study villages were surveyed to inform the MRC (2017e) study, with the most significant potential climate impacts expected to be though flood and drought, although in some cases river bank erosion and saline intrusion were also identified. Women, children and the elderly were considered to be the most vulnerable (MRC, 2017e).

4.6 Human health

No significant impacts on human health have been directly attributed to climate change to-date. It is anticipated that impacts on health due to climate change are most likely to be through vector-borne and water-borne disease and on maternal and child health as a result of heat stress, flood and drought, landslides and flash flooding.

USAID (2013) identify that health and infrastructure conditions are closely correlated and both are linked to more fundamental causal factors such as geographic location. A general trend of declining poverty levels in the LMB (Section 4.7) has been driven by, and contributed to improving health conditions. Life expectancy at birth has risen across all LMB countries (Figure 4.14) and child mortality has declined (Figure 4.15), albeit with significant regional variation. Nevertheless, key areas of community health identified as highly vulnerable to climate change are:

- Vector-borne and water-borne disease control, as a result of increased flooding
- Maternal and child health

Githeko *et al.* (2000) state that the impacts of climate variability on vector-borne diseases are relatively easy to detect; a result supported by work from Kien (2012) and Davies *et al.* (2015). However, this is not necessarily the case for the gradual impacts of climate change. Specific threats arise from temperature rise, flooding, flash flooding, and landslides (USAID, 2013). Projecting today's socio-economic conditions to future climate projections would see an increase in the incidence and extent of water- and vector-borne diseases. Floodplain, Delta, and Lowland plains and plateaus of the basin are considered to have the highest vulnerability to this particular impact (USAID, 2013).

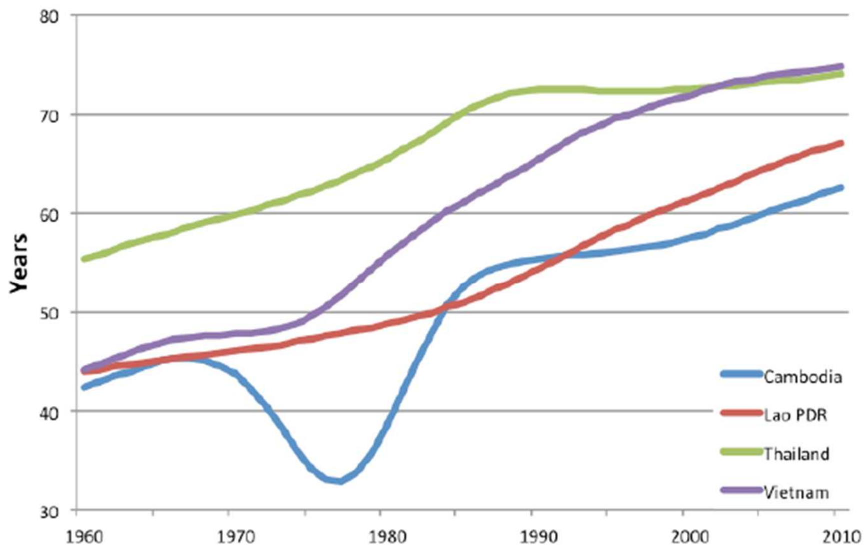


Figure 4.14: Life expectancy at birth in LMB countries (1960-2011) (WDI, 2013).

Maternal and child health issues are particularly prominent in Cambodia and Lao PDR and amongst ethnic minority groups with weaker access to social services. Impacts are mostly associated with heat stress, greater incidence of droughts, death and injury associated with landslides and flash floods, as well as flooding. Maternal and child health is also susceptibility to adverse shifts in food security with forested uplands considered to be the most vulnerable regions (USAID, 2013).

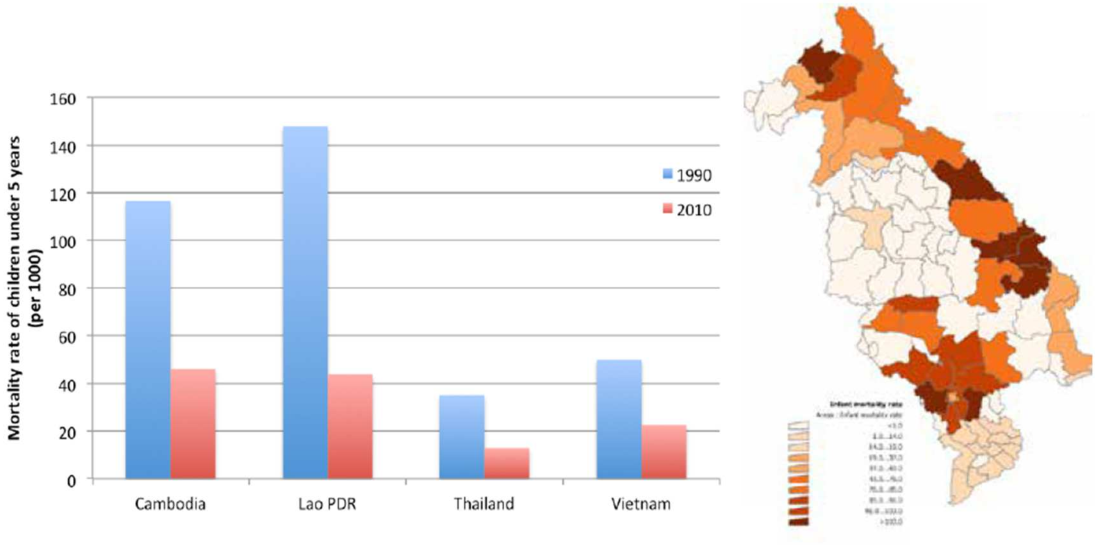


Figure 4.15: (a) Mortality rates of children under five in LMB countries; and (b) infant mortality by province (WDI, 2013 and MRC, 2015f).

ADB (2009) examined the projected impacts of climate change across Southeast Asia and concluded that climate change would have a significant impact on human health with modelling results showing that the number of deaths from thermal stress causing cardiovascular diseases would increase in the region. Those most likely to be affected were the elderly (above 65 years of age). Under the most pessimistic scenario heat-related cardiovascular and respiratory diseases in the region were projected to increase by +2.9% and +12.5% respectively by 2050 and +9.2% and +20.4% by 2100.

A number of studies have also looked at the potential impact of climate change on malarial transmission. For example, Caminade *et al*. (2014) demonstrate that globally there would be a net increase in climate suitability and therefore population at risk, although large parts of the LMB region would become less suitable for transmission. The results depend on the GCM and scenarios modelled and in any case Reiter (2001) suggests that the history of malaria, yellow fever, and dengue fever reveal the principal determinants of their range to be human activities and the impact on local ecology rather than climatic factors.

Further impacts on health may result from food and water-borne diseases in places subject to increased flooding, particularly in places where sanitation is poor. Davies *et al.* (2015) identifies diarrheal disease as the predominant water-borne disease following flooding in the past two decades in Cambodia. Other medical conditions following flooding include ear, nose and throat infections, wound infections, dermatitis and conjunctivitis.

4.7 Poverty, wellbeing, employment and income

No significant impacts on social conditions have been directly attributed to climate change to-date. On most indicators social and economic conditions are improving rapidly across all LMB countries. Poverty levels in particular have fallen dramatically, the population is more urbanized and fertility rates have fallen. However, many households and communities along the Mekong corridor remain vulnerable to shocks, particularly droughts and floods which can have a material impact on their livelihoods. Future climate change is likely to exacerbate the losses from extreme events particularly as the impacts of floods affect more people and droughts become longer and more frequent in some areas.

4.7.1 Past and current conditions

Since the early 1980s, the economies of Thailand and Viet Nam have grown rapidly, achieving average annual growth rates of around 5.4 per cent (Thailand) and 6.5 per cent (Viet Nam) between 1980 and 2010. In Cambodia and Lao PDR, economic development started to accelerate in the early 1990s following the launch of their economic reform programs. In both countries average economic growth rates of around 6.6 per cent per year were achieved between 1990 and 2010 (Figure 4.16).

The economies of LMB countries are expected to continue to grow at approximately 4 to 5 per cent per year, with all reaching middle income status by 2030, and high income status by no later than 2060. This forecast assumes the absence of major shocks and disasters, such as a regional economic crisis or the occasional major floods aggravated by climate variability and change.

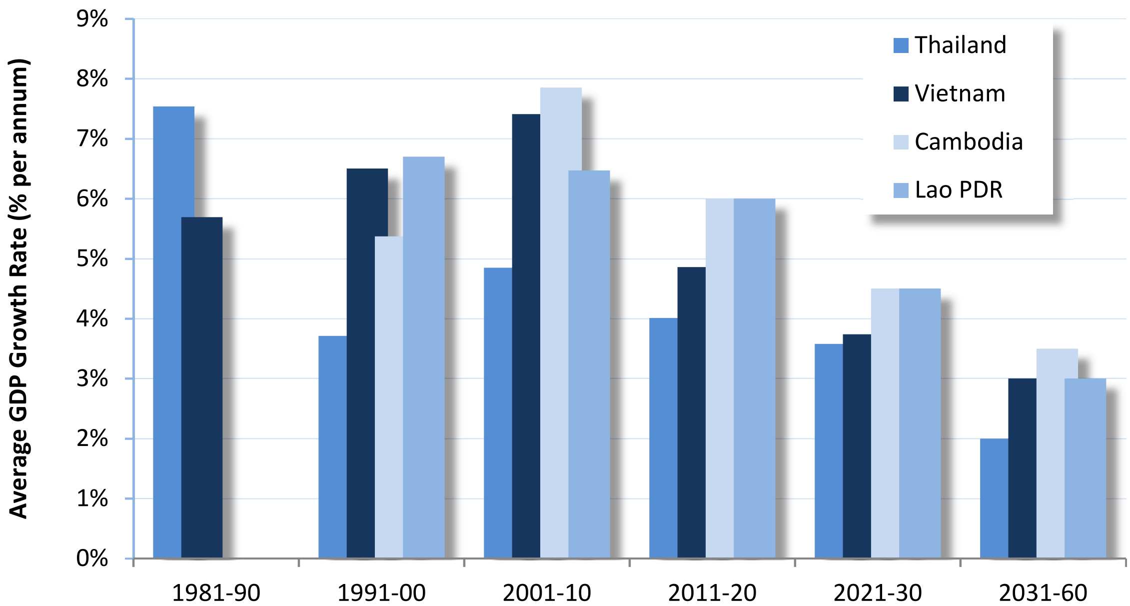


Figure 4.16: Average GDP growth rates per annum in LMB countries (MRC, 2016a).

With regard to per capita income, the rapid economic growth rates over the past 30 years have resulted in a very substantial improvement in Gross National Incomes (GNI) in LMB countries (Figure 4.17). Thailand is already a middle income country with a Gross National Income (GNI) per capita in 2013 of US$ 13,430, although the GNI per capita in the northeast of Thailand within the LMB is less than half of this amount. The GNI per capita of the basin within the other three countries (Cambodia US$ 2,890, Lao PDR US$ 4,550, Viet Nam delta US$ 5,070) is much closer to national averages.

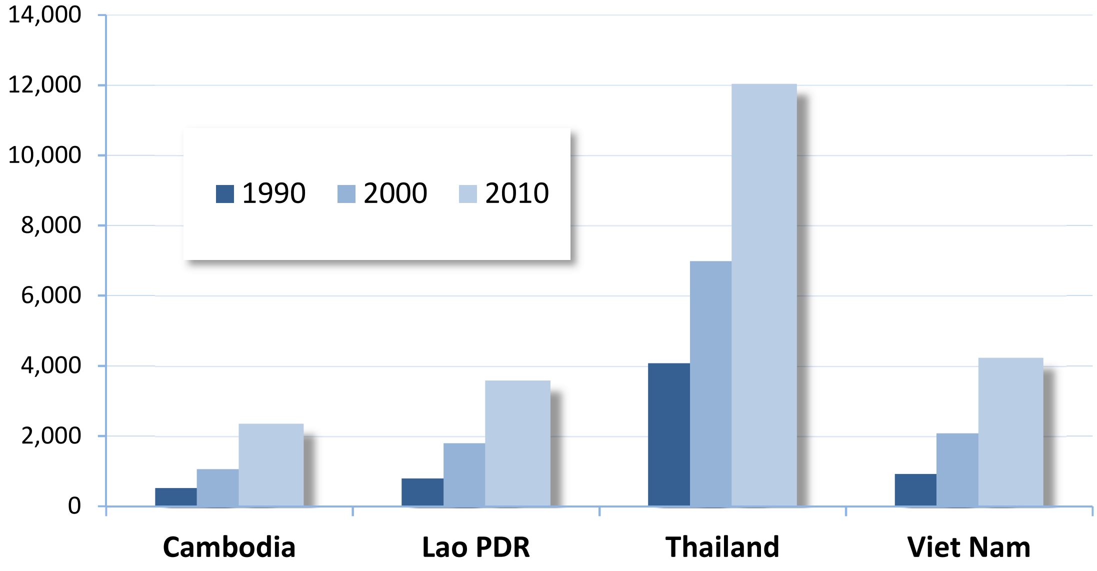


Figure 4.17: Gross National Income per capita in current US$ (whole country) (MRC, 2016a; *Source: World Bank* *http://data.worldbank.org/indicator*).

The most recent available population figures (2008-2012) show a total population of 64.8 million people living within the LMB. Compared to the previous estimate of 60.6 million, based on the 2005 Census (Lao PDR) and 2008 Census (other LMB countries), there has been an apparent population increase of 9%. Earlier population data showed a 14 per cent population increase from 1995-2000 to 2005-2008. The most populous provinces are found in Thailand, Viet Nam and on the floodplains in Cambodia.

The mean population growth rate for the provinces in the LMB is 1.24, but varies significantly from province to province. Overall, Cambodia and Lao PDR have population growth rates that lie above the mean for the LMB. In Viet Nam, available data show modest natural growth rates. In Thailand, some provinces have negative population growth rates, indicating low fertility rates and emigration.

Recent decades have brought with them a rapid demographic transition in the LMB countries with a sharp decline in fertility (see Figure 4.18a). Even Cambodia and Lao PDR, whose population growth rates are above the mean for LMB countries, have seen a fall in fertility rates to below the world average in recent years. Changing perceptions of the cost-benefit of having children, cultural factors, and changing gender roles provide an explanation for these changes.

Currently in the LMB countries, more than 60 per cent of the total population is younger than 30 years of age (62 per cent in Cambodia (2008) and 67 per cent in the Lao PDR (2012)). However, in the future there will be relatively more old people and less young people to provide for them. The sharp decline in fertility rates will slow LMB population growth. By 2060, the total population is projected to reach approximately 83 million, 20 per cent higher than at present.

In Southeast Asia as a whole, and to a lesser degree in the LMB countries, urbanization has been occurring at a rapid pace especially since 1990 and is likely to continue (see Figure 4.18b). In 1990, 16 per cent of the population in Cambodia resided in urban areas, in 2010 it was 20 per cent; in Lao PDR the figures were 15 per cent and 33 per cent, in Thailand 29 per cent and 44 per cent, and in Viet Nam 20 per cent and 30 per cent respectively (national figures). Thus, Lao PDR has seen the fastest urbanization rate with 18 per cent growth in the urban population over 20 years.

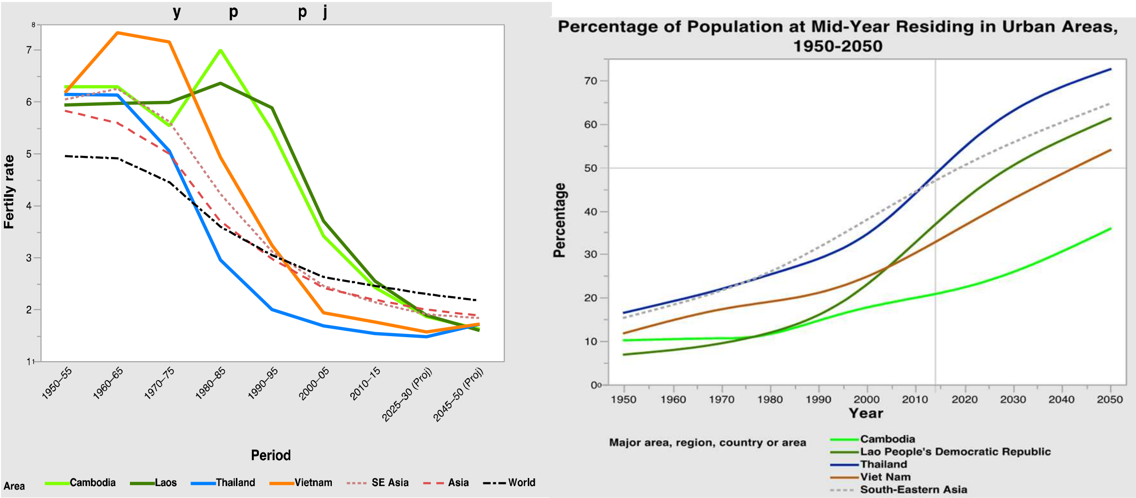


Figure 4.18: (a) Fertility rates areas across LMB countries relative to Southeast Asia, Asia and the World; and (b) percentage of total population residing in urban areas across LMB countries relative to Southeast Asia (MRC, 2016a; *Sources: United Nations World Population Prospects 2010 and 2014 Revisions*).

By 2060, between 50 per cent and 70 per cent of the people in Thailand, Viet Nam and Lao PDR and 35% in Cambodia, are expected to live in cities. The rural population in Cambodia is projected to remain stable around the current level of 10 million people, while the population in cities will continue to grow. In Lao PDR, the rural population is projected to decrease somewhat as cities grow and absorb the population growth. There has been a decrease in the total rural populations in Thailand and Viet Nam and this is projected to continue (Figure 4.19).

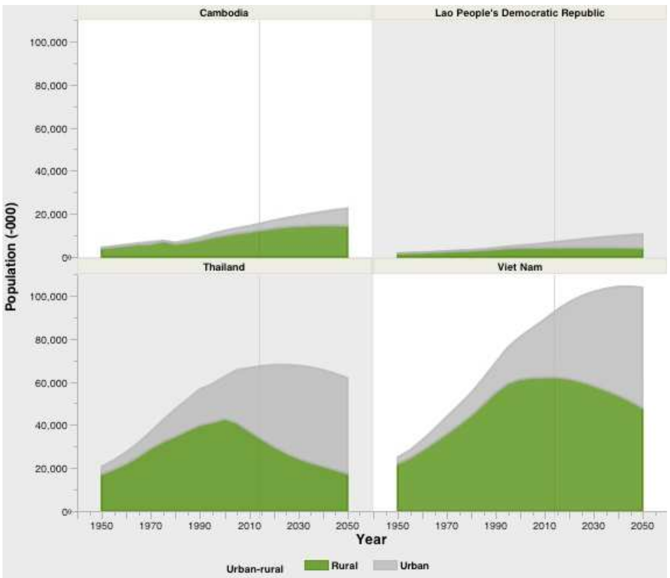


Figure 4.19: Rural and urban populations 1950-2050 by LMB country (MRC, 2016a; *Sources: United Nations Population Division 2014 Revision*).

Overall poverty levels have significantly reduced in LMB countries. In Viet Nam, the proportion of the population with income less than US$ 1.25 per day has decreased from 50% in 1995 to 17% in 2010 (Figure 4.20). The incidence of poverty has also reduced in Cambodia (from 45% to 23%), Lao PDR (49% to 34%) and Thailand (2.5% to 0.4%). There are significant variations between provinces, but these percentages are generally greater in rural areas compared to urban areas.

The focus on pro-poor economic growth and accelerated rural development could reduce the population below the poverty line further. By 2030, it is anticipated that the proportion of the population below the poverty line in Viet Nam, Cambodia and Lao PDR will be less than 8% (at US$ 1.25 per day).

With regard to income distribution, data on Gini coefficients (i.e. measure of statistical dispersion intended to represent national income distribution where 0 is perfect equality and 1 is perfect inequality) were collected. It is evident from Table 4.11 that income inequality remained broadly unchanged between 1995 and 2010 in Viet Nam, Cambodia and Lao PDR, and actually reduced in Thailand. In 2010, similar levels of income inequality prevailed across the LMB countries.

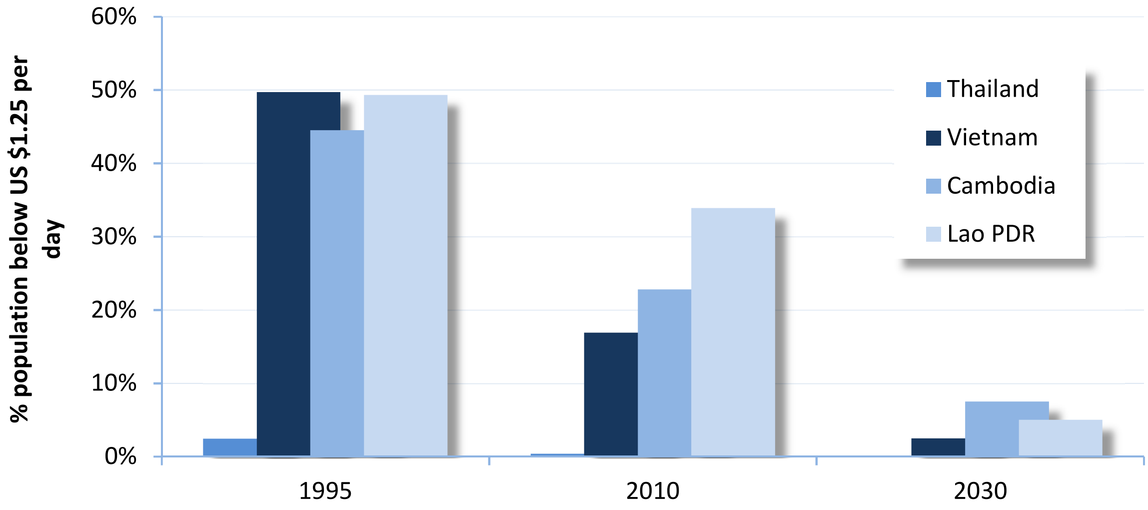


Figure 4.20: Proportion of the population below the poverty line in LMB countries (MRC, 2016a; *Source: World Bank* *http://data.worldbank.org/indicator*).

It is difficult to predict future changes in income inequality which are dependent on the rate of economic development, government programmes designed to reduce poverty, as well as measures to mitigate adverse impacts on low income groups.

Table 4.11: Incidence of poverty and income distribution (MRC, 2016a; *Source: World Bank http://data.worldbank.org/indicator and ADB: Key Indicators for Asia Pacific 2014*).

Country	% population with less than US$ 1.25/day		% population with less than US$ 2.00/day		Income Distribution Gini co-efficient	
	1995	2010	1995	2010	1995	2010
Cambodia	44.5%	22.8%	75.2%	49.5%	0.38	0.38
Lao PDR	49.3%	33.9%	79.9%	66.0%	0.35	0.37
Thailand	2.5%	0.4%	14.6%	4.1%	0.43	0.39
Viet Nam	49.7%	16.9%	85.7%	43.4%	0.36	0.36

Regional variations in household dependency ratio, household size, fertility rate and poverty rate are illustrated in Figure 4.21. Provinces in Cambodia and Lao PDR show much higher dependency ratios, household size, fertility rates and poverty rates than provinces in Thailand and Viet Nam. These factors are likely to make Cambodia and Lao PDR much more vulnerable to the impacts of climate change.

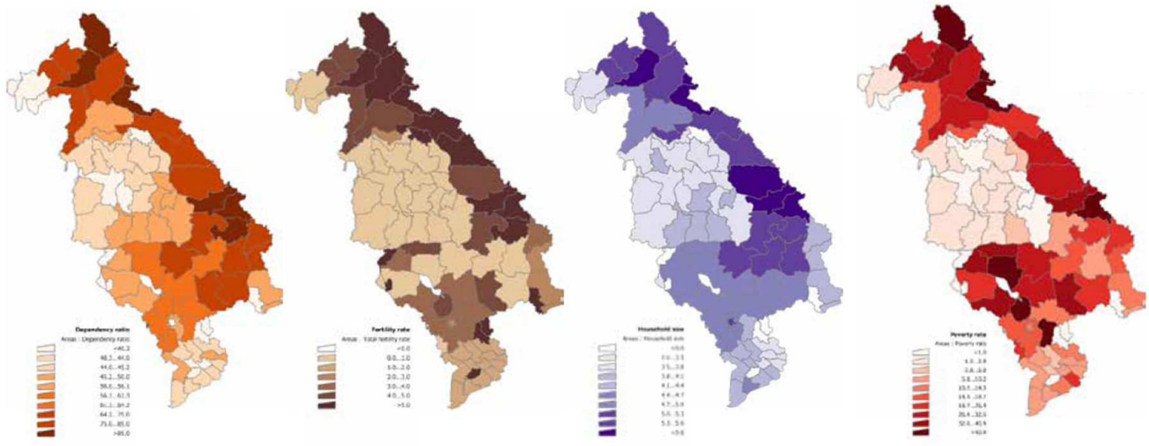


Figure 4.21: (a) Dependency ratio, (b) household size, (c) fertility rate; and (d) poverty rate, by province in LMB countries (MRC, 2015f).

Within the Mekong corridor information on occupations and livelihoods is collected through the MRC's Social Impact Monitoring and Vulnerability Assessments (SIMVA), three of which have been completed to date. The first, a pilot in 2010, then a baseline assessment in 2011, followed by an expanded assessment in 2014 (MRC, 2015f). According to the most recent report the main occupation of 59 per cent and secondary occupation of 7 per cent of the sample population was crop farming including gardening (Figure 4.22).

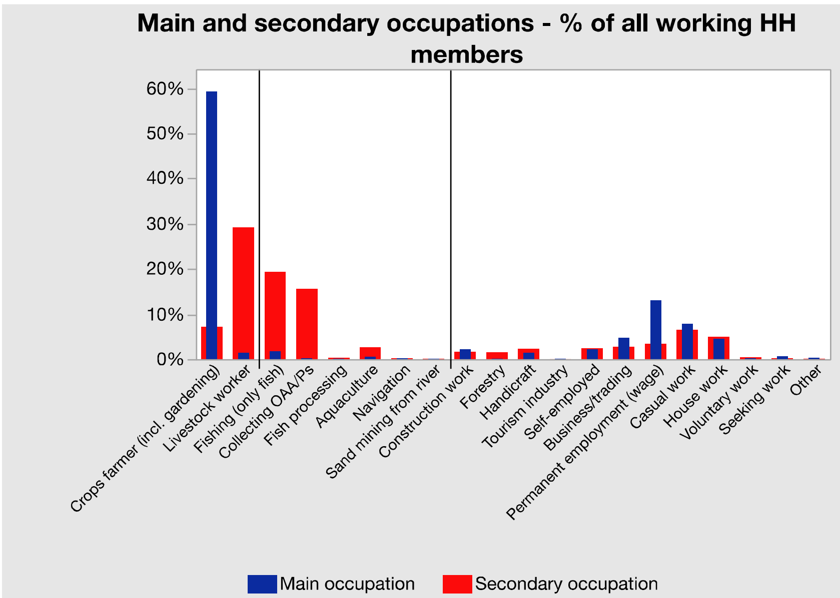


Figure 4.22: Main and secondary occupations for all household members (excluding dependents – children, elderly, students, disabled) – all LMB corridor. Vertical lines separate water resource dependent occupations from other occupations (MRC, 2015f).

Other important secondary occupations include livestock worker (29.2%), fishing (19%) and collecting Other Aquatic Animals and Plants (OAA/Ps) (15.5%). Full time fishing was the main occupation of only 2 per cent of the working age population and can therefore be considered mostly a part-time activity for a large majority of the population.

Nevertheless, fish are a fundamental part of peoples' livelihood. In the last 24 hours before the interview 75 per cent of the sample households had a meal with fish, 61 per cent consumed fish that was bought, while 31 per cent consumed fish from their own catch. The mean amount of fish cooked in meals in the last 24 hours before the interview was 0.23 kg per person. In addition, 41 per cent of the sample households had had a meal with OAA/Ps in the last 24 hours before the interview. In the latest meal that had included OAA/Ps, households on average cooked 0.33 Kg OAA/Ps per person, comprising 0.18 kg of aquatic animals and 0.15 kg of aquatic plants. Twelve per cent of the sample households had cultivated riverbank and island gardens and fields in the last 12 months. On average the households with riverbank gardens and fields sold 54% of the produce.

Omitting farming and livestock, an index of importance of different livelihood sectors was developed for SIMVA 2014 (MRC, 2015f). It illustrates that water resource dependent activities play an important role in peoples' livelihoods, on a par with wage earners in permanent employment (Figure 4.23). While there was no statistically significant difference in livelihood importance between sub-zones used for the SIMVA 2014 survey, the region around the Tonle Sap Lake in Cambodia and Songkhram in Thailand, both of which are characterized by extensive floodplains and wetlands, were identified as areas where water resource dependence was very important (MRC, 2015f). These results indicate the vulnerabilities of people along the Mekong River to climate change impacts on water resources.

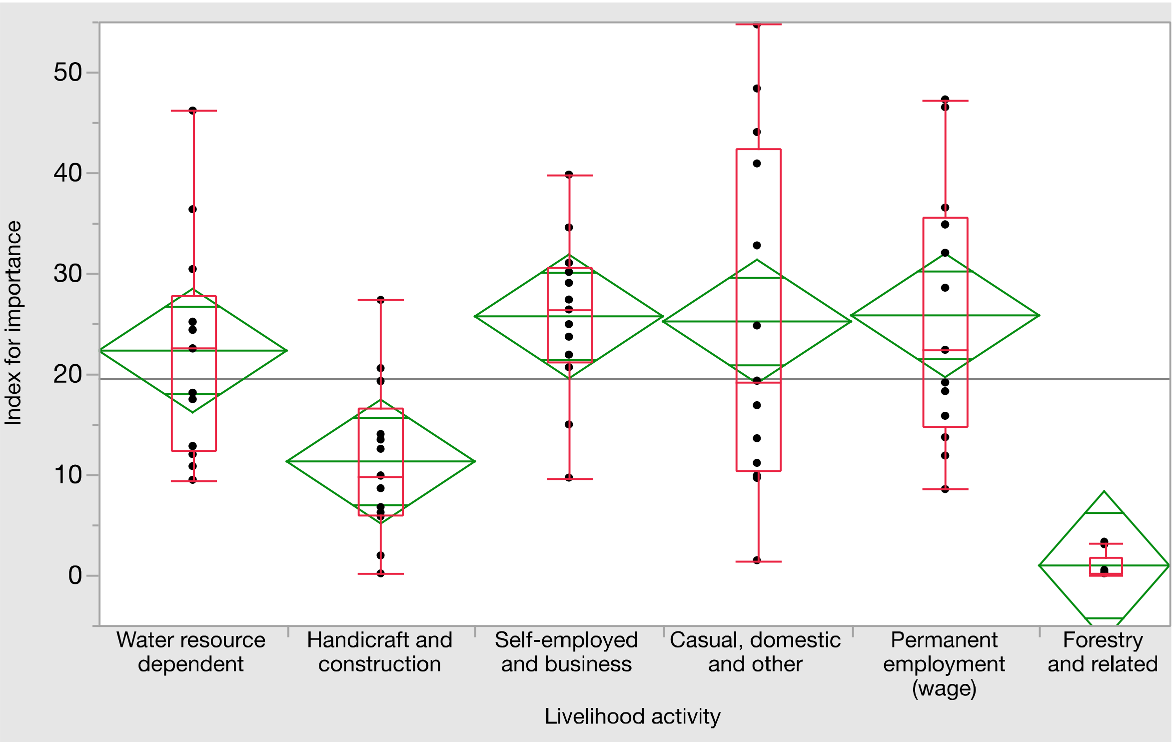


Figure 4.23: One-way analysis of Index of Importance of different categories of livelihood activity (MRC, 2015f).

While not attributable to climate change, 30 per cent of the sample households had experienced flooding in the last 12 months. Of those, 88 per cent had lost assets or experienced damages. The source of the most serious flooding was considered to be normal rains or monsoonal activity, as reported by 60 per cent of the households. Extreme weather or typhoons was the source of serious flooding reported by 14 per cent of the total sample.

Of the households that had experienced flooding in the last 12 months 61 per cent had lost or experienced damages to paddy land and rice production due to flooding. Affected households lost or had damaged 1.3 hectares on average, which was 59 per cent of their total paddy land area, and they lost 58 per cent of their usual production. The median value of lost rice per household was US$375 across the sample, with the mean value at US$ 598. Losses of production from riverbank and island fields across the sample was US$100 (median) and US$315 (mean).

Ten per cent of the flood-affected households had between 1 and up to 55 days without access to clean drinking water. Most of these households were in Cambodia (17% of the flood-affected households). Forty-six per cent of all the flood-affected households in the last 12 months reported loss of working days. Flooding also limited the access to sanitation for 18 per cent of the flood-affected households overall, in Cambodia 31 per cent, and in Viet Nam 15 per cent of the affected households.

Only 2.3 per cent of flood-affected households in last 12 months had aquaculture temporarily destroyed. The mean value of the production lost per household across the sample was US$ 385, highest in Cambodia at US$ 741 and between US$ 149 and US$ 215 in the other three countries. Very few households lost livestock due to flooding in the last 12 months. Less than 10 per cent of the households lost poultry. Only 10 per cent of flood-affected households also lost property, with an average value of US$454, highest in Thailand at US$ 838, lowest in Cambodia at US$175, with Lao PDR and Viet Nam at US$541 and US$394 respectively.

In the last 12 months before the survey 29% of the sample households had experienced drought, 60 per cent in Cambodia, 32 per cent in Thailand and 19 per cent in Lao PDR. 79 per cent of the drought-affected households had also lost assets. Half of the drought-affected households in the last 12 months lost paddy land and rice production, with 51 per cent of the total agricultural land affected on average, and the mean value of losses at US$454 per household, highest in Thailand at US$730, in Viet Nam US$644, in Lao PDR US$380, and in Cambodia US$368. Only 3 to 8 per cent of the surveyed households had lost cows, buffaloes or pigs and goats as a result of drought. For the 22 per cent of households that did lose assets due to drought in the last 12 months, the overall mean value of the losses was US$432, with a mean of US$454 for rice losses, US$ 350 for livestock and poultry, and US$695 for property losses.

These results illustrate that the population living in the Mekong River corridor is highly susceptible to economic losses resulting from both floods and droughts.

4.7.2 Projected climate change impacts and vulnerabilities

It has not been identified what impact climate change is likely to have on poverty, wellbeing, employment and income. However, much of the population is vulnerable to climate change given their reliance on natural resources and ecosystems for their livelihoods. As identified by USAID

(2013) '*the diverse components of rural livelihood systems are all dependent on healthy function natural systems*'.

The impact of climate change is likely at least in part to depend on the strategies that people have in place to cope with the change. Through the SIMVA studies (MRC, 2015f), vulnerability and coping strategies were assessed through village and household surveys. Work migration is one of the key SIMVA indicators for resilience. Almost all sample villages had people working outside their home village. The mean percentage of the village population that worked outside the village was 11 per cent, and highest in Songkhram in Thailand at 23 per cent. Around the Tonle Sap Lake 64 per cent of the villages reported having people working in another country. The survey found that the LMB corridor is a source of workers for other areas both within the country and in other countries.

Increased prevalence of flood and drought is likely to have a significant effect on livelihoods throughout the LMB, given the dependence on agriculture and on water resources mentioned earlier. The impact of climate change on floods depends in large part on the model applied (JBA, 2017). Under both the wetter overall model and the increased seasonality model the flooded area is projected to increase for floods of all return intervals. Under the drier overall model the flooded area is projected to decrease for all but the very largest of floods (1:500 and 1:1000 years). The biggest proportional changes are projected to occur for the smaller floods with return intervals of 1 in 2 years and 1 in five years (Table 4.12). Under the highest emissions scenario for the wetter overall model, the change projected to 2060 is an increase of 38 per cent for a 1 in 2 year flood. It is an increase of 27 per cent under the medium emissions scenario (Table 4.12).

Table 4.12: Percentage change in flooded area for ten different return interval events under a medium emissions scenario (RCP4.5) and the wetter overall (GFDL), drier overall (GISS) and increased seasonality (IPSL) models for 2030 and 2060 and including the high emissions (RCP8.5) scenario for 2060 (JBA, 2017).

	ISIS model	% Change	2030		% Change	2060		
Event	Flood Area (Ha)	GFDL 45	GISS 45	IPSL 45	GFDL 45	GISS 45	IPSL 45	GFDL 85
Q2	4,816,132	10.46	-5.37	5.80	27.30	-2.59	23.15	38.06
Q5	5,584,220	7.03	-3.83	4.58	20.21	-3.05	17.84	28.55
Q10	5,838,216	6.42	-2.78	4.79	18.50	-1.95	17.61	26.95
Q20	6,028,768	5.67	-1.77	4.79	17.22	-1.33	16.92	25.64
Q50	6,226,212	4.70	-1.18	5.12	15.75	-1.29	16.61	24.70
Q75	6,286,532	4.76	-1.74	5.24	15.33	-0.97	16.78	24.51
Q100	6,324,636	4.81	-0.83	5.35	15.33	-0.84	16.90	24.55
Q200	6,402,104	5.01	-0.09	5.49	14.95	-0.43	17.41	24.47
Q500	6,486,780	5.02	0.81	5.67	14.65	0.35	17.95	24.31
Q1000	6,549,372	4.97	1.07	5.89	14.29	0.72	18.16	24.48

The increase in flooded area using a composite model is projected to be highest in proportional terms in Viet Nam (at 24% and 31% in 2030 and 2060 respectively) but highest in area terms in Cambodia with an increase of more than 5 million hectares in both 2030 and 2060 (Table 4.13). The smallest increases in area are projected to occur in Lao PDR, but even there the increase is 9 per cent by 2030 and 18 per cent by 2060.

Table 4.13: Increase in flooded area in each LMB country using a composite of all models under medium (RCP4.5) and high emissions (RCP8.5) scenarios to 2060 (JBA, 2017).

Area Flooded (Ha)	Base Q100	2060 Med	2060 Extreme	Increase Area	Increase Area
Cambodia	5,009,360	5,383,096	5,667,144	7%	13%
Lao	3,105,288	3,382,004	3,654,076	9%	18%
Thai	3,439,312	3,686,108	4,012,840	7%	17%
Viet Nam	3,112,212	3,845,956	4,074,148	24%	31%
Total	14,666,200	16,297,200	17,408,200	11%	19%

The increase in flooding projected under these scenarios will affect more and more people. JBA (2017x) identify that under a medium emissions scenario by 2060 and extra 5.26 million people are expected to affected by flooding compared to the baseline. Under the high emissions scenario an extra 7.03 million people will be affected (Table 4.14).

Table 4.14: Increase in population affected in each LMB country using a composite of all models under medium (RCP4.5) and high emissions (RCP8.5) scenarios to 2060 (JBA, 2017).

Population Affected(millio	Base Q100	2060 Med	2060 Extreme	RCP 4.5 Increase (million)	2060 RCP8.5 Increase (m)
Cambodia	6.102	6.884	7.529	0.78	1.43
Lao	1.797	2.432	2.485	0.63	0.69
Thai	5.790	6.404	6.951	0.61	1.16
Viet Nam	13.334	16.565	17.086	3.23	3.75
Total	27.023	32.285	34.052	5.26	7.03

Coping strategies for the impacts of flooding, identified in the SIMVA studies (MRC, 2015f), varied across the LMB. Respondents to the surveys could choose from a number of possible coping strategies, but the most frequent response was 'Other', indicating the survey did not capture the actual coping strategy in these cases. Apart from 'Other', the most common coping strategies were borrowing money and receiving assistance from government. The most desperate coping strategy of selling productive assets was a coping strategy for around 10 per cent of the sample households, mainly in Cambodia.

The impact of climate change on the frequency and duration of droughts varies considerably depending on location within the LMB (MRC, 2017g). For example, the average percentage change in average annual drought frequency based on a Soil Moisture Deficit Index (SDMI), decreases in some areas and increases in others (Figure 4.24), with the upper Mekong Basin being particularly badly affected even by 2030. Large areas of the central LMB in Thailand and Cambodia are projected to have a reduction in drought frequency using a composite model, although this no doubt depends on the particular model applied.

Similarly, drought duration based on the SDMI is projected to decline across large areas of the basin in 2030 (Figure 4.24), although this reverses in many areas, especially along the eastern periphery and in the south-east, by 2060. MRC (2017g) apply a range of other drought indices which similar geographic variability in impacts.

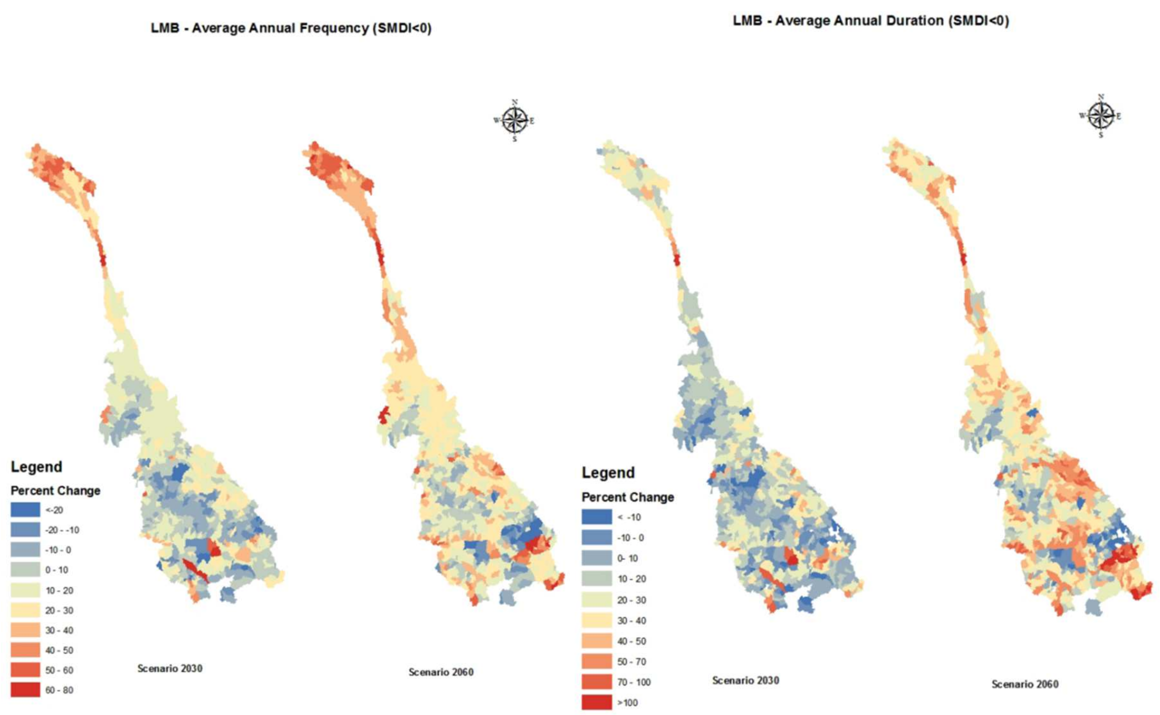


Figure 4.24: Average percentage change in average annual drought (a) frequency and (b) duration based on SDMI<0 across all climate models and emissions scenarios to 2030 and 2060 (MRC, 2017g).

Coping strategies for impacts of drought as identified in the SIMVA studies (MRC, 2015f) were very similar to the coping strategies identified for the impacts of flooding. The category 'Other' was the most common response, accounting for 34 per cent of all responses. Of the remaining coping strategies, borrowing money was the most common strategy, followed by receiving assistance from government. Adaptation to changing weather was found to be very limited in scale. Only 5 per cent of the sample households had changed the season for growing rice; another 15 per cent had changed to planting rice later, and 7 per cent of the households to planting earlier. Only 2 per cent of the households had changed crops due to drought, and 1 per cent had changed crops due to flooding. Only 0.3 per cent of the sample reported they had changed crops due to either falling or increasing temperatures.

The most significant economic values at risk from climate change in the LMB were identified to be worker productivity (Talberth and Reytar, 2014), especially for workers employed in outdoor occupations such as agriculture, forestry, fishing and construction. This is because outdoor workers are likely to be exposed to a greater incidence and severity of health disorders including heat rash, transient heat fatigue, heat syncope, heat cramps, heat exhaustion and heat stroke (Roy et al., 2011). Globally, reduced labour productivity due to climate change and increased humidity is estimated at 20% by 2050 (Dunne *et al.,* 2013). Talberth and Reytar (2014) estimate the annual value at risk across all four LMB countries as US$8,371 million in 2013 dollars.

With regard to alternative livelihood options, the SIMVA survey found that 70 per cent of the sample households in the LMB corridor had not thought about alternative livelihood options. However, the need to consider alternatives to their present livelihood appeared to be a present concern for 30 per cent of the population.

Chapter 5: Adaptation

5.1 Policy and institutional response

Policy and institutional response to climate change is an important part of the enabling environment for adaptation actions at all levels of society. The key national policies and strategies and institutional arrangements for mainstreaming climate change are identified in Table 5.1 as reported by Member Countries in National Communications to the United Nations Framework Convention on Climate Change (UNFCCC).

Table 5.1: Key national policies and strategies and institutional arrangements for mainstreaming climate change adaptation.

Country	Key national policies and strategies	Institutional arrangements
Cambodia	▫ Cambodia Climate Change Strategic Plan 2014-2023 ▫ Strategic National Action Plan for Disaster Risk Reduction 2008-2013 ▫ National Strategic Development Plan 2006-2010 ▫ Pilot Programme on Climate Resilience (PPCR)	▫ National Council for Sustainable Development (NCSD)[17] ▫ Climate Change Department, within the Ministry of Environment
Lao PDR	▫ Lao PDR National Strategy on Climate Change 2010, drawn from a number of sectoral strategies[18] ▫ Seventh National Socio Economic Development Plan (NSEDP-7)	▫ National Environment Committee ▫ Department of National Disaster Management and Climate Change within the Ministry of Natural Resources and Environment
Thailand	▫ Thailand National Climate Change Strategy ▫ 10th National Economic and Social Development Plan	▫ National Climate Change Committee ▫ Ministry of Natural Resources and Environment
Viet Nam	▫ National Climate Change Strategy 2011 ▫ National Environment Protection Strategy ▫ Viet Nam Sustainable Development Strategy	▫ National Steering Committee for the UNFCCC and Kyoto Protocol ▫ Ministry of National Resources and Environment

The UNFCCC has been ratified by all four Member Countries and in accordance with their obligations, each country has now submitted at least two National Communications to the Convention. Consistent with UNFCCC guidelines these National Communications acknowledge the importance of climate change adaptation and stress the need for increased research in order to develop and implement effective response measures. They address measures necessary for sectors including agriculture, forestry, health, water resources and coastal resources. Under the Kyoto Protocol, which all four Member Countries have also ratified, parties are encouraged to develop national (and regional) adaptation programs.

Under the UNFCCC, a work program for Least Developed Countries (LDC) was established from 2001 and included the development by each country of a National Adaptation Programme of Actions (NAPA). The main content of the NAPA is a list and short profile of ranked priority adaptation activities, designed to facilitate the development of project proposals for implementation. Priority

[17] From May 2015 has taken over functions of the National Climate Change Committee

[18] National Environment Strategy, Forest Strategy, Agriculture Strategy, Strategy for Water Resources Development, Energy Strategy, National Disaster Strategy

sectors addressed are agriculture and food security, water resources, coastal zones and early warning and disaster management. NAPA's submitted to the UNFCCC enable a country access to the LDC Fund to support implementation. Both Cambodia and Lao PDR have submitted NAPAs to the Convention.

At a regional level the Climate Change and Adaptation Initiative of MRC is developing a Mekong Adaptation Strategy and Action Plan (MASAP) which will seek to provide guidance on mainstreaming adaptation, particularly transboundary, measures across the LMB. The MASAP will be informed by the basin-wide assessments of climate change on water and water related resources and sectors in the LMB and a review of existing practical measures across member countries.

A policy review undertaken by MRC (MRC, 2016b) to ascertain the enabling environment for adaptation actions found that:

- National policies are in place but in some cases are in potential conflict with other socio-economic strategies in particular sectors
- Policies at a national level are focused at government administration and public awareness and action and less so at the private sector, which has a potentially important role to play
- Improved information exchange and knowledge sharing would be beneficial both within and between countries
- National coordination generally occurs through national climate change committees. There may be some room for simplification of governance structures to improve coordination and effectiveness
- Climate change awareness in countries is generally low, both within government and amongst the broader public
- Financing for climate change adaptation is growing within the national budgets and there is an important role in ensuring this expenditure is coordinated with funds from international assistance programmes
- Regional institutions such as ASEAN and MRC both give priority to climate change work and the importance of cooperation between member countries on the subject. They provide a mechanism for cooperation and transboundary regional action

5.2 Adaptation capacity

5.2.1 Global Water Partnership Reports

According to the Global Water Partnership Southeast Asia (GWPSEA, 2010), adaptation capacity can be considered both in terms of adaptive capacity – that is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007); and coping capacity – that is the means by which people or organisations use available resources and abilities to face adverse consequences that could otherwise lead to disaster.

Barriers to adaptive capacity were considered across all LMB countries. In Cambodia, the NAPA (2006) identifies the following barriers:

- Limited financial resources or funding for climate change related activities, especially in the health and agriculture sectors
- Few climate change studies and little experience within the country;
- Lack of climate change research and/or training institutions in the country;
- Lack of data availability and reliability and , in particular, absence of a formal mechanism for information sharing;
- Limited cooperation and coordination among institutional agencies related to research or studies on climate change and climate variability;
- Relatively low technical capacity of local staff;
- Relatively low government salary and limited incentives from the climate change project;
- Non-comprehensive national climate change policies and/or strategy;
- Lack of qualified national experts in the country;
- Limited public awareness and education on climate change; and
- Limited technical, financial and institutional resources for adaptation.

In Lao PDR, problems and weaknesses were summarised as (GWPSEA, 2010):

- Lack of Hydro-met stations that cause of inadequate data information
- Lack of experience, knowledge and data
- Limited local experts on the climate change management
- Lack of financials
- Inadequate capacity building
- Weak public awareness and communication
- Floods and Droughts
- Increase Water borne diseases
- Effected Food security especially fishery

In Thailand, the following gaps were identified (GWPSEA, 2010):

- Lack of awareness on climate change.
- Awareness and Institutional strength and capacity on climate change.
- Adaptation capacity.
- Technical knowledge among government agencies and NGOs working on environment and impacts of climate change.
- Reliable climate change data and Analytical studies on climate change impacts

While in response to issues identified within Viet Nam, work is being implemented to (GWPSEA, 2010):

- Assess climate change impacts to water;
- Strengthen governance of water resources based on the IWRM and river basin management principles;
- Increase efficiency of agricultural water usage and safety of irrigation facilities;
- Enhance drinking water supply;

- Implement integrated coastal management; and
- Focus on Disaster prevention.

5.2.2 National Communications to the United Nations Framework Convention on Climate Change

Within their national communications to the United Nations Framework Convention on Climate Change (UNFCCC), countries have identified the following limitations and constraints to climate change adaptation.

Cambodia

Constraints and gaps to climate change adaptation include limited human capacity, the lack of reliable and comprehensive datasets and research in preparing a national greenhouse gas inventory, inadequate mitigation analysis and vulnerability assessments, a lack of technology awareness, policy and institutional shortfalls and significant financial constraints.

Human resource capacities relate to lack of knowledge and information on crop diversification and market engagement; and professional expertise across Ministries and relevant government institutions with greater effort required on teaching and research. In addition, there is a shortage of technical experts to undertake climate risk modelling, impact assessment and development of adaptation measures. Further research and analysis is required across a range of areas including:

- Flooding impacts, especially around Mekong River and Tonle Sap
- Extensification, intensification and diversification of rice production measures
- Better understanding of potential rainfall impacts
- The interaction of climate change with development impacts such as new dams etc.
- The impacts of climate change on the incidence of malaria
- The impacts of natural disasters on macroeconomic and budgetary performance

Cambodia identified the importance of technology transfer and investment, including in:

- Household safe water supply
- Rainwater harvesting from rooftops
- Wells, small reservoirs, small dams and micro-catchments for community water supply
- Mangrove management

Cambodia identified not only that there are inadequate financial resources, but also a lack of financial mechanisms in place to implement adaptation and mitigation options.

Lao PDR

Issues in responding to climate change identified by Lao PDR include:

- Concern about the lack of priority given to climate change relative to other concerns
- Lack of systems in place to monitor and evaluate actions
- Ensuring international development cooperation and foreign investment is aligned with sustainable development, the green economy and climate change strategies and plans
- Capacity to develop a longer term climate change path

- Research and capacity development
- Policies and mechanisms for securing finance to address climate change priorities

Key issues identified in adaptation included:

- the need for more appropriate national climate scenarios to assess impacts and vulnerability
- lack of long-term historical data
- lack of long-term, comprehensive studies on sectoral impacts especially on agriculture, water resources, forests and public health
- lack of long-term socio-economic scenarios to assess vulnerability and adoption of adaptation measures
- shortage of technical experts
- weak local ownership of NAPA projects and need for accelerated implementation of projects

Lao PDR identified that technology transfer is inhibited by high up-front costs; lack of expertise; insufficient research and development; lack of integration of climate change needs in national technology development and innovation process, issues with property rights etc. Research and systematic meteorological observation are also required but are hampered by limited technical and human resources.

Lao PDR identified that awareness and capacity building is required at all levels, from public awareness, education in schools, international negotiations, research and learning amongst academics, scientists and researchers. However, technological limitations are inhibiting the flow of information; there is a need for a strengthened national focal point; and there is insufficient networking of key stakeholders particularly amongst the private sector and civil society.

Thailand

Issues in responding to climate change identified by Thailand include:

- Need more climate change scenarios that are appropriate to the sub-region
- Develop techniques for preparing socio-economic scenarios that are consistent with climate change
- Techniques for analysing impacts on major sectors and for prioritising adaptation options
- Introduce public health warning systems in critical areas
- Technologies required for: disaster warning systems; coping with coastal erosion; agricultural forecasting and warning systems; develop climate change resistant plant varieties
- Develop public health and disaster risk management systems in disaster-prone areas
- Promotion of climate scenarios in planning for different sectors especially agriculture, water resources and health

Thailand also refers to the need to enhance the capacity of climate change negotiators, as well as meteorologists, including through regional information exchange and communications.

Viet Nam

Viet Nam identified the following issues in responding to climate change:

- Need better resolution climate models to understand local impacts
- Database of impact assessments and adaptation measures is incomplete
- More in-depth analysis to distinguish between climate change and other impacts
- Adaptation impact assessment and response measure development models and tools are insufficient, in particular for cross-sector or inter-regional assessments
- Assessment of technological needs for adaptation lacks capacity, methodology and database
- Lack of technical experts
- Existing hydro-meteorological observational infrastructure and telecommunication systems are insufficient and lack uniformity
- Limited technical and human resource capacity
- Education curricula not well developed across all levels
- Broad lack of awareness of climate change
- Technology transfer needs
- Requirement to mobilise domestic and international funds and develop long-term financing plans

5.3 Examples of adaptation in practice

There are a multitude of climate change adaptation measures being implemented across the Lower Mekong Basin. As of early 2016, the CCAI database of climate change adaptation projects identified 28 such projects in Cambodia, 34 in Lao PDR, 79 in Thailand, and 25 in Viet Nam across a range of sectors and at varying spatial scales. Projects include those to better integrate climate change considerations in policies and strategies as well as on-ground investment in infrastructure to improve resilience. As an example, in Ben Tre province in Viet Nam, as part of a larger strategy a local dam was constructed across the Tien River to capture freshwater and allow farmers to grow rice, vegetables, fruit and other cash crops all year round. The intention of this project was to improve productivity and nutrition, diversify livelihoods and improve health through access to fresh water, benefiting approximately 4,000 people. Another example, this time from Lao PDR, sought to build community resilience to disasters by improving income security, diversifying livestock and improving crop production, and by improving the capacity to communicate information about disasters and disaster management in local languages. Additionally, much investment in research and understanding the impacts of climate change on different sectors and regions has been undertaken.

More broadly, the extent of climate change adaptation response across the Lower Mekong Basin can be considered by evaluating the following parameters:

Total flood protected area: Areas protected against floods (partially or fully) provide protection also against the risk of higher floods caused by climate change. Assessments in 2010 suggest that by 2020, notwithstanding increased regulation of mainstream flows, flooded areas could increase by up to 6%. Further assessments are being made as part of the MRC's Council Study with the latest climate change predictions, which may alter these estimates.

Total irrigation area: Irrigation provides farmers with the capacity to withstand drought periods and to ensure that planting is done at appropriate dates. As noted in chapter 4, irrigated harvest areas have been steadily increasing, rising from about 3.1Mha in 1995 to about 4.7Mha in 2013, equivalent to a year-on-year increase of 2.4%. The estimated irrigated areas in 2013 are summarised in Table 5.1. As may be seen, as far as rice and maize, the two main food grain crops, are concerned just over a third of the area had access to irrigation.

Table 5.1: Total irrigation area in 2013 (MRC, 2016a; *Source: MRC estimates*).

Total irrigation area rice + maize (hectares)	
▫ Cambodia	428,777
▫ Lao PDR	90,962
▫ Thailand	356,514
▫ Viet Nam	3,887,295
Total	**4,763,548**
Rain-fed area	9,279,244
Total rice + maize area	**14,042,793**
Percent with irrigation	*34%*

Total water storage: Reservoir storage operation re-regulates stream flows, taking out peaks and slowly releasing flows downstream. Reservoirs in the Mekong Basin are mostly operated for the purpose of hydropower operation, which generally seeks to maximise energy output, for which the aim is to ensure the maximum carry over of storage from wet to dry season. This leads to sub-optimal flood protection, particularly in the instance of floods occurring later in the wet season. Nevertheless, all reservoirs contribute to some degree to reducing flood peaks and the risks of flooding downstream.

The volume of live storage in the Mekong Basin is increasing, as illustrated in Table 5.2. As may be seen by 2020 and beyond total storage available exceeds 14% of the river's mean annual runoff (MAR). However, in the near term, a large proportion of that storage is located in the UMB on the Lancang River in China. However, the most severe flood-causing rainfall generally occurs in northern Lao PDR and the highlands of Viet Nam and therefore where major new storages are planned after 2020.

Table 5.2: Live reservoir storage in the Mekong Basin (Mm^3) (MRC, 2016a; *Source: MRC hydropower database, 2015).*

Year	Cambodia	Lao PDR	Thailand	Viet Nam	China	Total	Percent of MAR
2000	0	1,773	3,100	781	257	**5,910**	1%
2020	2,600	24,257	3,399	2,752	23,293	**56,301**	14%
2040	13,060	45,761	3,399	3,165	23,293	**88,678**	22%

Coverage of disaster warning system: MRC hosts the Regional Flood Warning Centre in Phnom Penh which provides a service throughout the wet season to monitor and forecast mainstream floods. Warnings are disseminated through the MRC website and through relevant ministries, and the coverage may be seen as applying throughout the annually flooded areas in Cambodia and Viet Nam, an area of approximately 43,000 km^2 in which the highest population densities of the Basin can be found.

There are a range of additional adaptation options available to Lower Mekong Basin countries. Some of these have been identified through studies such as the Mekong ARCC project (Table 5.3) while countries themselves have identified options across a range of sectors in their national communications to the UNFCCC (Table 5.4).

5.4 Economics of adaptation and adaptation options

One way to consider the costs and benefits of adaptation is by assessing the values at risk from climate change. Talberth and Reytar (2014) used this approach as part of the Mekong ARCC project. Rather than seeking to determine exactly what the potential change in value might be over time with complex interactions between multiple economic sectors, the values at risk approach simply seeks to understand the total economic value of resources at risk. Talberth and Reytar's (2014) analysis demonstrated that the minimum annual values at risk in the LMB are roughly US$16 billion per year. Work productivity was the most significant value at risk, accounting for more than half of the total (Table 5.3).

Table 5.3: Summary of the Minimum Annual Values at Risk from climate change in the Lower Mekong Basin, excluding infrastructure assets (from Talberth and Reytar, 2014).

Values at risk component	Mean VAR-($2013-mil)
Non-agricultural infrastructure services	$3,426.67
Worker productivity	$8,370.67
Crop production	$2,545.75
Hydro-electric power generation	$434.17
Ecosystem services	$1,240.85
Totals	**$16,018.11**

In total the value at risk represents 7% to 30% of rural GDP within the LMB (PPP adjusted; Talberth and Reytar, 2014). If added to at-risk infrastructure this increases to 14% to 61% of rural GDP. Given the value at stake, the authors conclude that significant investments in adaptation measures such as workplace heat assessments and protection measures, eco-resilient cropping techniques and green infrastructure for storm surge protection are clearly warranted.

Climate Vulnerability Monitor estimates that overall magnitude of expected damage from climate change in the four LMB countries to be a net economic cost of US$364 billion annually by 2030 (DARA, 2012). The biggest losses are associated with reduced labour productivity, followed by rising sea levels and impacts on coastal zone infrastructure and agriculture and fisheries.

Table 5.4: Summary of adaptation options by sector and country as identified through the Mekong ARCC project (USAID, 2013).

<table>
<tr><th></th><th>Cambodia</th><th>Lao PDR</th><th>Thailand</th><th>Viet Nam</th></tr>
<tr><td rowspan="2">Agriculture</td><td colspan="4">- Strengthening the resilience of both rain-fed and irrigated rice-based systems through adoption of improved varieties and better management practices and reducing vulnerability to extreme climate events. This could include the use of specific varieties to mitigate the impact of flooding and extreme heat, as well as the shifting of cropping calendars to avoid harvest during periods of high rainfall.
- Improving soil fertility and soil management of both cash and subsistence systems such as improved erosion control techniques and intercropping.
- Promoting agricultural diversification and mixed farming systems to mitigate current trends of reliance on monocultures.</td></tr>
<tr><td></td><td></td><td></td><td>- Adopting/improving water efficiency and water management practices (water harvesting, small–scale irrigation, etc.) in drought-prone areas such as in the Central Highlands in order to alleviate the impacts of water shortages.</td></tr>
<tr><td>Livestock</td><td colspan="4">- Nutrition: The quality and quantity of feed production, storage, and the nutritional balance of diets needs to be increased to reduce undernourishment.
- Disease resistance: Internal resistance needs to increase to reduce the threat of disease through improvement of nutritional status, body condition, and vaccination levels. It also requires improved biosecurity to prevent the movement of diseases onto and off farms and to reduce the risk of pathogens entering the herd or flock.
- Housing: Location and design should maximize natural ventilation and minimize exposure to extreme events.
- Production planning and offtake: Reducing inbreeding, earlier weaning, and strategic offtake plans can increase resilience of livestock systems.
- Access to markets: Improved access to input and output markets and producer organizations would reduce input costs, increase prices received, and reduce price volatility</td></tr>
<tr><td rowspan="2">Fisheries</td><td colspan="4">- Pond aeration to mitigate the effects of increased temperature;
- On-site water storage to reduce the risks of reduced water availability during the dry season;
- Strengthening of embankments to protect against flooding will be necessary for ponds in many areas; and
- Construction of diversion canals to channel water away from vulnerable pond areas.</td></tr>
<tr><td></td><td></td><td></td><td>- More climate-friendly systems, (e.g. tiger shrimp/crab production in mangrove replanted areas of the delta), should be utilized and promoted more widely.</td></tr>
</table>

Table 5.5: Summary of adaptation options by sector and country as identified in National Communications to the UNFCCC.

	Cambodia	Lao PDR	Thailand	Viet Nam
Water Resources		- Raise awareness on water and water resource management - Map flood-prone areas - Establish an early warning system for flood-prone areas, and improve and expand meteorology and hydrology network and weather monitoring systems - Strengthen institutional and human resource capacities related to water and water resource management - Survey underground water sources in drought-prone areas - Study, design and build multi-use reservoirs in drought-prone areas		- Formulate plans for sustainable water resources development of all river basins and regions based on the national social and economic development planning. - Reinforce, upgrade and complete the existing structures and add new water resource exploitation and utilization infrastructure - Reinforce and upgrade the existing system of river and sea dykes and build a water-pump and drainage system in low-lying areas and coastal flood-prone areas - Promote water use efficiency and conservation - Upgrade and modernize the observation and long-range water resources forecasting network and develop flood warning systems - Raise public awareness
Coastal zone	- Re-design of long-lived infrastructure to account for the impacts of climate change			- Upgrade 2,700 km of the existing sea and estuarine dykes - Elevate land and residential infrastructure - Pump and dewater - Protect coastal environments - Establish community-based adaptation funds - Develop flood maps
Agriculture	- Increasing the capacity to use climate information, such as the use of climate forecast information, in setting up better cropping strategies and agribusiness activity; - Implementing adaptation measures which also contribute to emission reduction, such as the introduction of technology that increase water use efficiency via the System of Rice Intensification (SRI); - Creating additional sources of income for communities from co-benefits of mitigation activities, such as generating carbon credits from reforestation or the use of manure and biomass waste (e.g. biogas for cooking and biomass energy in rice mills, composting, etc.).	- Strengthen the capacities of National Disaster Management Committees - Promote secondary professions to improve the livelihoods of farmers affected by natural disasters induced by climate change		- Prevent soil erosion, implement soil protection, preserve soil moisture and fertility levels - Provide proactive irrigation to crops by constructing water reservoirs and adopt more efficient irrigation methods - Select crops adaptable to climate change - Adjust the growing seasons and sowing times as appropriate - Adopt new, more suitable cultivation practices - Expand fodder production and enhance storage, processing and utilization of animal feeds - Build stables with adequate designs, proper manure and wastewater treatment systems - Adopt climate change-suited cropping patterns - Crossbreed to create new species more adaptable to the changing climate with

	Long-term efforts will be directed at increasing the resilience of the agriculture system to future climate risks through the revitalization of long-term policies and planning that take into account climate change. Key long-term activities include: o Institutionalizing the use of climate information in agriculture management and development; o Prioritizing structural intervention programmes (where and when a particular intervention should o be in place to minimize the impact of increasing climate risk, such as constructing dams or irrigation schemes); o Expanding agriculture areas to regions with lower climate risk; o Creating climate insurance for vulnerable communities; o Generating more varieties resistant to drought, flood and high salinity; - Developing and implementing long-term research on climate modelling, mitigation and adaptation technologies.		increased tolerance for arid conditions, high salinity, flooding and pests - Modernize cultivation and stockbreeding techniques - Adopt scientific, efficient water management methods - Improve land management capacity - Re-plan regional patterns of crop and livestock production - Provide additional incentives for agriculture, forestry and aquafarming - Forecast crop output, develop disaster and pest warning systems in agriculture, and improve information and communication systems - Provide crop and livestock insurance - Develop and implement climate change adaptation mechanisms and policies
Forestry	- Proposed protected areas in the northeast and northwest of Cambodia	- Continue a slash-and-burn eradication programme and a permanent job creation programme - Strengthen the capacity of village forestry volunteers in forest planting, caring and management techniques, as well as in the use of village forests	- Strengthen sustainable forest management and development - Conduct research to select and diversify plant species resistant to droughts, floods, pests and less prone to causing forest fires. Establish genetic conservation plans and gene banks - Develop a forest fire control and management program, and strengthen infrastructure for fire forecasting, warning and control - Enhance timber-use efficiency, and develop timber and non-timber product processing technologies - Implement coastal mangrove forest system restoration and development projects, plant protective dune forests - Support livelihood and improve living conditions for people living near forests

Aquaculture			- Design aquaculture plans for different ecological zones - Develop plans to preserve marine biodiversity and ecologies - Introduce heat-tolerant varieties in aquafarming - Improve capacity in the management of aquafarming infrastructure - Construct more storm shelters for fishing ships - Upgrade the existing and develop new aquaculture logistic services sites - Study and forecast fish school movements, improve the capacity in weather forecast information accessibility for fishermen - Establish aquaculture insurance funds
Energy and transportation			- Mainstream climate change issues into energy and transportation development strategies and plans - Promote efficient energy use and energy conservation - Improve energy efficiency - Elevate and renovate structures in the energy and transportation sectors in areas vulnerable to sea-level rise and flooding - Reinforce transportation infrastructure, power transmission structures in high flood-prone, mountainous and sloping areas
Health	- Reducing the number of malaria cases; and - Reducing the number of deaths caused by malaria	- Improve systems for the sustainable use of drinking water and sanitation. with community participation, in flood- and drought- prone areas - Improve knowledge and skills of engineers who design and build water and sanitation systems	- Review construction standards and regulations to take into account meteorological loading and urban sewage - Strengthen residential planning with respect to natural disasters impacts for vulnerable areas - Build capacity for rural healthcare institutions in disaster-prone areas - Develop disease, epidemic, and air pollution outbreak forecasting capacity. Integrate disease forecasting into the national weather forecast - Control vector-borne, water-borne and food-borne diseases - Promote climate change and epidemics research and information dissemination

At the local level, MRC (2016h) identified a range of existing adaptation options in twelve case study villages across the LMB, although some being more widespread than others. These included:

- Introduction of new rice varieties: early rice varieties (90 days); drought resistant varieties for dry season; flood resilient type for flood season;
- Selection of more drought tolerant crops;
- Changing cropping patterns to improve climate tolerance;
- Adapting a more flexible cropping calendar;
- New rice growing methods such as direct seeding, or System of Rice Intensification;
- Improvement of soil conservation;
- Use of manure to improve soil fertility and crop production;
- Improve irrigation system and irrigation efficiency;
- Well construction i.e. groundwater development;
- Water pond or small reservoir construction, building dikes for water ponding;
- Pond water harvesting using water for vegetable production and/or fish rising;
- Improving the efficiency of water use;
- Vegetable garden (homestead size);
- Improvements in livestock and animal husbandry management;
- Improvement of fishery management;
- Supplementary catching fish from the river, canals or ponds (owning fishing gear);
- Fostering of non-timber forest products as supplementary food source;
- Reforestation and forest rehabilitation;
- Changing occupation during the idle season;
- Seek work locally as day labourer, or out migration to towns and cities for some time;
- Credit lines are provided during and after a disaster;
- Ongoing capacity building on new and innovative agricultural technologies; and
- Forming of disaster prevention youth groups at a village level and assigning specific tasks.

Chapter 6: Conclusions

6.1 Key findings

Climate change in the Lower Mekong Basin is already evident. Average annual basin-wide temperatures and precipitation are rising, albeit with regional variations. The impact of these changes on natural resources and socio-economic systems has not yet been determined with any certainty. However, projected future climate changes and the resulting impacts on water resources, biodiversity and ecosystems, vegetation and forests, and fisheries are in some scenarios extreme. The implications for socio-economic systems may be profound with vulnerable communities being those most dependent on natural resources for their livelihoods. As identified in this Status Report:

- Average annual basin-wide temperatures and precipitation have increased over the historical record. Sea-level around the Mekong Delta is rising. Regional climate change is not a future phenomenon, it is already occurring.
  - There are nevertheless regional variations, with areas in the north of the basin and around the Delta becoming drier and areas around Tonle Sap and the southern highlands becoming wetter, particularly during the wet season.
  - There is no evidence to-date of more intense rainfall events or more frequent or intense tropical storm activity.
- The hydrology of the Mekong River is changing. Dry season flows are higher and wet season flows lower. This change is most evident in the upper reaches of the Mekong with the effect diminishing downstream, but is unlikely to be the result of climate change. Changes have been principally attributed to up-stream flow modifications by the construction of dams in the Upper Mekong Basin.
- Over recent decades there have been very significant changes in vegetation cover, forests, biodiversity and ecosystems across the Lower Mekong Basin. Large areas of natural vegetation and forests have been lost or significantly degraded, the number of threatened species is increasing, species populations are in decline and natural wetlands have been heavily modified if not destroyed. However, it is not possible from the existing information to determine the relative contribution of climate change to these changes.
  - The impact from legal and illegal logging, clearing for agriculture and urban areas, flow modification, and over harvesting amongst a range of other pressures are a more significant cause of the changes observed to-date.
- Changes to capture fisheries are uncertain. While overall catch appears to be increasing, the composition of the catch is changing with some species in decline, others increasing, and smaller fish making up a greater portion of the overall catch. Catch-per-unit-effort is declining suggesting there are more people chasing fewer fish. It is not possible at this point in time to determine if climate change has contributed to any of these changes.

While there is evidence that the climate of the region is already changing, becoming hotter and wetter, there is a wide range of potential future changes projected to occur over the next 15 to 45 years:

- Temperatures are projected to increase across the basin and across seasons. The only real uncertainty is the magnitude of the increase and how quickly it occurs. By 2060 the average annual basin-wide increase could be as low as 0.3˚C or as high as 3.3˚C depending on the global emissions trajectory that is followed.

- Rainfall could increase or decrease and with significant variation in the magnitude of change and the location of impacts. Average basin-wide change in dry season rainfall is projected to vary between -23% to +23% by 2060 and wet season rainfall between -18% to +16%. Regional variations are likely to see much wetter average annual conditions in the north of the basin under the wetter overall scenario, and drier average annual conditions from the north, over the Khorat plateau and across the Tonle Sap region, in the drier overall scenario.
- Variations in hydrology will follow changes in precipitation and a similarly wide range of future impacts is possible. Overall basin water yield, annual river flow and level, wet season duration, peak flow and level, and dry season minimum flow and level, could all either increase or decrease depending on the emissions trajectory and the climate change model which is ultimately most accurate. The range in possible outcomes is enormous with annual river flow changing by between -59% and +33%, and dry-season minimum one-day flow changing by between -65% and +42% at Chiang Saen under climate change only scenarios. Basin development will interact with the impacts from climate change, in some cases exacerbating the change and in some cases mitigating against it.

The contribution of climate change to past and current changes in socio-economic systems has not been determined with any certainty. There are too many other factors at play. However, projected changes are potentially very significant and many people and communities are vulnerable to potentially wide-ranging impacts.

- Agricultural yields are likely to be affected with the negative impacts outweighing the positive. Potential declines in rice yields are of particular concern. Planned increases in irrigation, changes in agricultural practice and technological improvements are likely to be required to offset these impacts.
- Yields from fisheries and aquaculture are also vulnerable with climate change impacts on aquaculture expected to be more significant than impacts on capture fisheries due to rising sea-levels, salinity intrusion and the impacts of increased temperatures, and floods and droughts on smaller ponds and reservoirs.
- Hydropower production is at risk due to increased droughts, while navigation may be affected by lower dry season flows making some parts of the upper Mekong impassable at certain times of year. Roads and water supply infrastructure are at risk from more intense rainfall, increased flooding and landslides, while significant expenditure may be required to protect coastal infrastructure from rising sea levels and storm surges.
- Overall food security has improved significantly in recent decades, the health of the population is better, poverty levels have fallen dramatically, the population is more urbanised and fertility rates have fallen. However, many households and communities along the Mekong corridor remain vulnerable to shocks, particularly droughts and floods which can have a material impact on their livelihoods. Future climate change is likely to exacerbate the losses from extreme events.
- Without action to mitigate the impacts, the costs of climate change could be significant with large parts of the economy at risk; however, the impacts will not be felt evenly as some people and communities are more exposed than others or will experience the changes

sooner or to a greater extent. Provinces in Cambodia and Lao PDR are generally more vulnerable due to higher dependency ratios and higher poverty rates, especially in the north of the LMB, and around Tonle Sap and the southern highlands.

There are broad economic and structural changes occurring across Lower Mekong Basin countries which will help to mitigate the impacts of climate change (e.g. economic growth, urbanisation, reducing poverty and improving health and infrastructure). However, some policies may be in conflict with adaptation measures such as resource extraction policies which degrade natural ecosystems, reducing their buffering capacity. Despite the changes that have occurred, many people are still very reliant on natural systems for their livelihoods and food security, which makes them more vulnerable to impacts on these systems. The capacity to adapt and remain resilient in the face of climate change will depend on a range of factors including how diversified livelihoods are and the assets and resources available to households to cope with shocks.

There are nevertheless many barriers to effective adaptation within Lower Mekong Basin countries. Through their National Communications to the United Nations Framework Convention on Climate Change, all countries have identified issues with:

1. a lack of human resources capacity
2. regional scenarios and information on climate change impacts being inadequate
3. data and information gaps
4. a lack of financial resources and the mechanisms for financing action on climate change
5. insufficient technology transfer and required investment
6. a lack of awareness both within government at different levels, and across the community on potential climate change impacts and adaptation options

Despite this capacity deficit, there are many examples of climate change adaptation being enacted within countries across the region and according to their National Communications, recognition that there is a need to do much more. Access to international finance and regional cooperation and knowledge sharing will play an important role in achieving these ambitions.

6.2 Recommendations

Understanding the current status of climate change and adaptation in the Lower Mekong Basin is an important pre-requisite to preparing for the future. This requires good systems in place to monitor and report on change as it occurs and to place this change within the context of future potential trajectories. It is proposed that MRC Member Countries give consideration to:

- the development of a consistent set of indicators to evaluate climate change impacts over time. This first report has been based on the information available through a range of different and disparate sources and would be enhance by a more consistent and systematic approach over time. An initial set of proposed indicators is provided in Appendix A as described in MRC (2017h).

- having a monitoring system in place to collect data on climate change impacts across sectors related to those indicators would further support efforts to understand the trajectory of the Basin with regard to climate change and its impacts.

- undertaking some targeted studies, where feasible, to evaluate specifically what impacts have already occurred due to climate change, particularly on natural resources such as biodiversity and ecosystems, vegetation and forests and fisheries. In many sectors it has not been possible to determine the contribution of climate change, if any, to the overall change already being observed in the condition of natural resources and socio-economic systems. There are too many other influencing factors.

- Establish mechanisms to evaluate the effectiveness of adaptation actions and lessons learned in their implementation.

The wide-range of projected impacts across water and water-related sectors on the basis of equally plausible climate scenarios, with potentially different impacts in different parts of the Basin, means that it is essential to identify and implement adaptation policies that:

- have broad socio-economic benefits and rationale, essentially supporting good practice and sustainable development pathways and ensuring resilience to shocks whether they be due to climate change or other causes (e.g. global market volatility, natural disasters – whether or not they become more frequent);
- are flexible and scalable – the direction and magnitude of change cannot be known with certainty. All we know is that significant change is very likely to occur. It is important that communities can deal with change regardless of how it manifests itself and can rapidly scale-up the response as change becomes more evident and severe;
- support improved governance and strengthened institutions that allow for participatory approaches and enhanced decision-making capacity for individuals and communities – a one-size-fits-all approach is unlikely to succeed given the variation in potential impacts across the Lower Mekong Basin and so awareness and access to information is critical for household and business decisions;
- support a diversification of income sources and livelihoods wherever possible, so that people have options at times when they really need them; and
- provide for information (including monitoring and early-warning) and capacity building, which is essential to enabling good decisions at all levels of government and community.

REFERENCES

Adamson, P. 2006. *An evaluation of Land use and Climate Change on the Recent Historical Regime of the Mekong*. Mekong River Commission, Vientiane, Lao PDR.

ADB, 2011. *Guidelines for climate proofing investment in the transport sector: Road infra-structure project*s. Asian Development Bank, Mandaluyong City, Philippines

ADB, 2013. *Increasing Climate Change Resilience of Urban Water Infrastructure (Guidebook*). Asian Development Bank, Mandaluyong City, Philippines.

Adger, W.N., Arnell, N.W. and Tompkins, E.L. 2005. Successful adaptation to climate change across scales. *Global Environmental Change,* 15: 77-86.

ADPC, 2003. *Climate Change Protection Programme Climate Change and Development in Vietnam: Agriculture and Adaptation for the Mekong Delta Region*. Asian Disaster Preparedness Centre.

Anthony, E.J., Giochot, M., Brunier, G., Dussouillez, P., Provansal, M. and Dolique, F. 2013. Widespread erosion of the Mekong River Delta: from construction to destruction phase?

Arias, M.E., Cochrane, T.A.m Piman, T., Kummu, M., Caruso, B.S. and Killeen, T.J. 2012. Quantifying changes in flooding and habitats in the Tonle Sap Lake (Cambodia) caused by water infrastructure development and climate change in the Mekong Basin. *Journal of Environmental Management*, 112: 53-66.

Bhagabati, N.K., Ricketts, T., Sulistyawan, S. B., Conte, M., Ennaanay, D., Hadian, O., McKenzie, E., Olwero, N., Rosenthal, A. and Tallis, H. 2014. Ecosystem services reinforce Sumatran tiger conservation in land use plans. *Biological Conservation*, 169: 147-156.

Blöschl, G. and Montanari, A. 2010. Climate change impacts - throwing the dice? *Hydrological Processes,* 24: 374–381.

Boonpragob, K., Santisirisomboon, J., 1996. Modeling potential changes of forest area in Thailand under climate change. In: *Climate Change Vulnerability and Adaptation in Asia and the Pacific*. Springer, pp. 107–117.

Carr, J.A., Outhwaite, W.E., Goodman, G.L., Oldfield, T.E.E. and Foden, W.B. 2013. *Vital but vulnerable: Climate change vulnerability and human use of wildlife in Africa's Albertine Rift*. Occasional Paper of the IUCN Species Survival Commission No. 48. IUCN, Gland, Switzerland and Cambridge, UK.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J. and Mitchell, R.B. 2003. Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America,* 100: 8086-8091.

Chaudhry, P. and Ruysschaert, G. 2007. *Climate change and Human development in Vietnam: a case study (No. 2007/46)*. Human Development Report for the United Nations Development Program.

Chinowsky, P.S., Schweikert, A.E., Strzepek, N.L., Strzepek, K. 2012. *Road Infrastructure and Climate Change in Vietnam*. WIDER Working Paper 2012/80. UNU-WIDER, Helsinki, Finland.

Cochrane, T.E. Arias, M.E. and Piman, T. 2014. Historical impact of water infrastructure on water levels of the Mekong River and Tonle Sap system. *Hydrology and Earth System Sciences*, 18: 4529-4541.

DARA. 2012. *Climate Vulnerability Monitor, Second Edition: A Guide to the Cold Calculus of a Hot Planet*. Available at: http://daraint.org/climate-vulnerability-monitor/climate-vulnerability-monitor-2012/executive-summary/.

Deb, P., Tran, D.A. and Udmale, P.D. 2015. Assessment of the impacts of climate change and brackish irrigation water on rice productivity and evaluation of adaptation measures in Ca Mau province, Vietnam. *Theoretical and Applied Climatology*, 1–16.

Ding, X., Zheng, D., Chen, Y., Chao, J., and Li, Z. 2001. Sea level change in Hong Kong from tide gauge measurements of 1954–1999. *Journal of Geodesy*, 74: 683–689.

Eastham, J., Mpelasoka, F., Mainuddin, M., Ticehurst, C., Dyce, P., Hodgson, G., Ali, R., Kirby, M. 2008. *Mekong River Basin Water Resources Assessment: Impacts of Climate Change*. CSIRO: Water for a Healthy Country National Research Flagship.

Emanuel, K., Sundararajan, R., and William, J. 2008. Hurricanes and Global Warming: Results from Downscaling IPCC AR4 Simulations. *Journal of Climate,* 89: 347-367.

Esteban, M., Takagi, H., Nguyen, D.T. 2014. *Tropical Cyclone Damage to Coastal Defenses: Future Influence of Climate Change and Sea Level Rise on Shallow Coastal Areas in Southern Vietnam*.

FAO, 2008. Climate Change and Food Security - A Framework Document. Food and Agriculture Organisation of the United Nations. Available at: http://www.fao.org/forestry/15538-079b31d45081fe9c3dbc6ff34de4807e4.pdf.

Ficke, A.D., Myrick, C.A., Hansen, L.J. 2007. Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries*, 17: 581–613.

Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In: Vié, J.-C., Hilton-Taylor, C., Stuart, S.N. (Eds.). *The 2008 review of the IUCN Red List of Threatened Species.* IUCN, Gland, Switzerland.

Foden, W.B., Butchart, S.H.M., Stuart, S.N., Vié, J-C., Akçakaya, H.R., Angulo, A. *et al.* 2013. Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. *PLoS ONE,* 8(6): e65427.

Grinsted, A., Moore, J. C., and Jefrejeva, S. 2009. Reconstructing Sea Level from Paleo And Projected Temperatures 2000 to 2100 AD. *Climate Dynamics*, 34: 461–472.

Halls, A.S. and Johns, M. 2013. *Assessment of the vulnerability of the Mekong Delta Pangasius catfish industry to development and climate change in the Lower Mekong Basin*. Report prepared for the sustainable fisheries partnership 2013.

Halls, A.S., Paxton, B.R., Hall, N., Peng Bun, N., Lieng, S., Pengby, N. and So, N. 2013a. *The Stationary Trawl (Dai) Fishery of the Tonle Sap-Great Lake, Cambodia*. MRC Technical Paper No. 32, Mekong River Commission, Phnom Penh, Cambodia.

Halls, A.S., Paxton, B.R., Hall, N., Hortle, K.G., So, N., Chea, T., Chheng, P., Putrea, S., Lieng, S., Peng Bun, N., Pengby, N., Chan, S., Vu, V.A., Nguyen Nguyen, D., Doan, V.T., Sinthavong, V., Douangkham, S., Vannaxay, S., Renu, S., Suntornratana, U., Tiwarat, T. and Boonsong, S. 2013b. *Integrated Analysis of Data from MRC Fisheries Monitoring Programmes in the Lower Mekong Basin*. MRC Technical Paper No. 33, Mekong River Commission, Phnom Penh, Cambodia.

Hammer, G.L., Nicholls, N. and Mitchell, C. (Eds). 2000. *"Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems - The Australian Experience",* Kluwer Academic Publishers.

Hanh, P.T.M., Anh, N.V., Ba, D.T., Sthiannopkao, S. and Kim, K-W. 2010. Analysis of variation and relation of climate, hydrology and water quality in the lower Mekong River. *Water Science and Technology*, 62: 1587 – 1594.

Hapuarachchi, H.A.P., Takeuchi, K., Zhou, M.C., Kiem, A.S., Georgievski, M., Magome, J. and Ishidaira, H. 2008. Investigation of the Mekong River basin hydrology for 1980–2000 using the YHyM. *Hydrological Processes*, 22: 1246–1256.

Hayman, P.T. 2000: Communicating probabilities to farmers: pie charts and chocolate wheels. In: *A manual of tools for participatory R&D in dryland cropping areas* (Eds: Petheram, R.), Rural Industries Research and Development Corporation. Available online at: https://rirdc.infoservices.com.au/items/00-132, p. 133-136, Canberra, Australia.

Hayman, P.T., Crean, J., Parton, K.A. and Mullen, J.M. 2007. How do seasonal climate forecasts compare to other innovations that farmers are encouraged to adopt? *Australian Journal of Agricultural Research,* 58: 975-984.

Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. *MRC Technical Paper,* 16: 1-88.

Hortle, K.G. and Bamrungrach, P. 2015. *Fisheries habitat and yield in the Lower Mekong Basin*, MRC Technical Paper No 47, Mekong River Commission, Phnom Penh, Cambodia.

Hughes, A.C., Satasook, C., Bates, P.J.J., Bumrungsri, S. and Jones, G. 2012. The projected effects of climatic and vegetation changes on the distribution and diversity of Southeast Asian bats. *Global Change Biology*, 18(6): 1854-1865.

ICEM, 2010. *Climate Change Baseline Assessment Working Paper*. Meteorological Department of Thailand.

Imamura, F. and To, D. 1997. Flood and typhoon disasters in Viet Nam in the half century since 1950. *Natural Hazards*, 50: 71 – 87.

Inomata, H. and Fukami, K. 2008. Restoration of historical hydrological data of Tonle Sap Lake and its surrounding areas. *Hydrological Processes*, 22(9): 1337-1350.

IPCC, 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, 2014. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core writing team, R.K. Pauchauri and L.A. Meyer (eds.)] Intergovernmental Panel on Climate Change, Geneva, Switzerland, 151 pp.

Jacobs, K., Garfin, G. and Lenart, M. 2005. More than just talk: connecting science and decision making. *Environment: Science and Policy for Sustainable Development,* 47: 6-21.

JBA, 2017. *Enhancement of basin-wide flood analysis and additional simulations under climate change to provide datasets for impact assessment and MASAP preparation (Stage 1)*. LBA Consulting

JMA, 2012. *Annual Report of the Tokyo Typhoon Agency, 2012*. Japan Meteorological Agency, Tokyo.

Kam, S.P., Teh, L., Tran, N., Teh, L. and Badjeck, M.-C. 2012. *Autonomous adaptation to climate change by shrimp and catfish farmers in Vietnam's Mekong River delta*. (Working paper No. 2012-24). WorldFish

Kiem, A.S. and Austin, E.K. 2013a. Drought and the future of rural communities: opportunities and challenges for climate change adaptation in regional Victoria, Australia. *Global Environmental Change,* 23(5): 1307-1316.

Kiem, A.S. and Austin, E.K. 2013b. Disconnect between science and end-users as a barrier to climate change adaptation. *Climate Research,* 58: 29-41.

Kiem, A.S. and Verdon-Kidd, D.C. 2011. Steps towards 'useful' hydroclimatic scenarios for water resource management in the Murray-Darling Basin. *Water Resources Research,* 47.

Klorvuttimontara, S., McClean, C.J. and Hill, J.K. 2011. Evaluating the effectiveness of protected areas for conserving tropical forest butterflies of Thailand. *Biological Conservation*, 144(10): 2534-2540.

Koutsoyiannis, D., Efstratiadis, A., Mamassis, N. and Christofides, A. 2008. On the credibility of climate predictions. *Hydrological Sciences Journal,* 53(4): 671–684.

Koutsoyiannis, D., Montanari, A., Lins, H.F. and Cohn, T.A. 2009. Climate, hydrology and freshwater: towards an interactive incorporation of hydrological experience into climate research—DISCUSSION of "The implications of projected climate change for freshwater resources and their management". *Hydrological Sciences Journal,* 54(2): 394–405.

LDD Thailand, 2000. *Soil Loss Map of Thailand*. Land Development Department Ministry of Agriculture and Cooperatives, Bangkok.

Mainuddin, M., Hoanh, C.T., Jirayoot, K., Halls, A.S., Kirby, M., Lacombe, G., Srinetr, V. 2010. *Adaptation Options to Reduce the Vulnerability of Mekong Water Resources, Food Security and the Environment to Impacts of Development and Climate Change*. CSIRO.

Mainuddin, M., Kirby, M., Hoanh, C.T. 2011. Adaptation to climate change for food security in the lower Mekong Basin. *Food Security*, 3: 433 – 450.

Mainuddin, M., Kirby, M., Hoanh, C.T. 2012. Water productivity responses and adaptation to climate change in the lower Mekong basin. *Water International*, 37: 53–74.

McKeon, G., Hall, W., Henry, B., Stone, G. and Watson, I. 2004. *"Pasture Degradation and Recovery in Australia's Rangelands: Learning from History",* Queensland Department of Natural Resources, Mines, and Energy, Brisbane, Australia, 256 pp.

Meinke, H., Nelson, R., Kokic, P., Stone, R., Selvaraju, R. and Baethgen, W. 2006. Actionable climate knowledge: from analysis to synthesis. *Climate Research,* 33: 101–110.

Meinke, H., Howden, M., Struik, P.C., Nelson, R., Rodriguez, D. and Chapman, S.C. 2009. Adaptation science for agriculture and natural resource management- urgency and theoretical basis. *Current Opinion in Environmental Sustainability,* 1: 69-76.

Mendelsohn, R., Emanuel, K. and Chonabayashi, S. 2009. *The Impact of Climate Change on Global Tropical Storm Damages.* Available online at: http://ase.tufts.edu/econ/events/seminars/2009-2010/mendelsohnClimateChange.pdf

Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Sayre, R., Trabucco, A. and Zomer, R. 2013. A high-resolution bioclimate map of the world: a unifying framework for global biodiversity research and monitoring. *Global Ecology and Biogeography*, 22: 630–638.

MONRE Viet Nam, 2009. *Climate change, sea level rise scenarios for Viet Nam*. Ministry of Natural Resources and Environment, Vietnam.

MONRE Viet Nam, 2012. *Revised Official Climate change scenarios for Vietnam,* Hanoi, Vietnam.

Montanari, A., Blöschl, G., Sivapalan, M. and Savenije, H. 2010. Getting on target. *Public Service Review: Science and Technology,* 7: 167-169.

MRC. 2001. *Metadata for MRC Secretariat GIS Core Datasets*. (Commission MR, ed.). Phnom Penh, Cambodia.

MRC, 2003. *State of the Basin Report 2003*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2009. *Annual Mekong Flood Report 2008*. Mekong River Commission, Flood Management and Mitigation Programme, Vientiane, Lao PDR.

MRC, 2010a. *Impacts of climate change and development on Mekong flow regime*. First assessment – 2009. MRC Technical Paper No. 29. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2010b. *Annual Mekong Flood Report 2009*. Mekong River Commission, Phnom Penh, Cambodia. 80 pp.

MRC, 2010c. *Assessment of basin-wide development scenarios. Technical Note 9: Impacts on Wetlands and Biodiversity (for discussion)*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2010d. *State of the Basin Report 2010*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2011a. *Assessment of basin-wide development scenarios.* Main report for the Basin Development Plan Programme, Phase 2. Mekong River Commission, Vientiane, Lao PDR.

MRC. 2011b. *Planning Atlas of the Lower Mekong River Basin*. Basin Development Plan Programme. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2014a. *Basin-wide assessments of climate change impacts on water and water related resources and sectors in the Lower Mekong Basin*. Technical Note No. 1. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2014b. *Crop production for food security and rural poverty: baseline and pilot modelling*. Mekong River Commission, Phnom Penh. Cambodia.

MRC, 2015a. *Review of approaches for developing climate change scenarios and addressing scenario uncertainties in adaptation planning for the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015b. *Climate Change Atlas of the Lower Mekong Basin.* Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015c. *Implementation report of the PMFM for 2011-2012.* The Procedures for the Maintenance of Flows on the Mainstream (PMFM). Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015d. *Wetlands in the Lower Mekong Basin: Basin-wide climate change impact and vulnerability assessment*. ICEM Australia; Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015e. Fisheries habitat and yield in the Lower Mekong Basin. MRC Technical Paper No. 47. Mekong River Commission, Phnom Penh, Cambodia.

MRC, 2015f. *Social Impact Monitoring and Vulnerability Assessment 2014: Shocks and Trends*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015g. *Development trends and future outlook in the Lower Mekong Basin countries*. Working Document: Basin Development Plan Programme. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015h. *Guidelines for the evaluation of hydropower and multi-purpose portfolios*, Annex 1, Economics Practice Guide. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2015i. *Design of a master plan for regional waterborne transport in the Mekong River Basin*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2016a. *Preparatory State of the Basin Report 2016*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2016b. *Regional report on overview of policy for climate change and adaptation in the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2016c. *Climate change impacts on hydrology of the Lower Mekong Basin – Volume 1: water level, flow and salinity*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2016d. *Flood and drought behaviour during the baseline period 1985-2008*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2016e. *Land cover map of the Lower Mekong Basin*. MRC Technical Paper No. 59. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2016f. *Assessment of the impact of climate change on fisheries resources under different climate change conditions and scenarios in the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR [DRAFT REPORT].

MRC, 2017a. *Projected Climate Change and impact on bioclimatic condition and terrestrial ecosystems in the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2017b. *Basin-wide climate change vulnerability assessment of Lower Mekong Basin species*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2017c. *Basin-wide impacts of climate change on ecosystem services*. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2017d. *Assessment of basin-wide impacts of climate change on ecosystems and biodiversity within the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR [DRAFT REPORT].

MRC, 2017e. *Basin-wide assessment of climate change impacts on food security and adaptation options in the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR [DRAFT REPORT].

MRC, 2017f. *Change in hydropower production under climate change*. Presentation to regional consultation workshop on basin-wide assessments of climate change impacts on hydrology, flood behaviour, drought behaviour and hydropower in the Lower Mekong Basin on 30-31 March 2017. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2017g. *Lower Mekong Basin Drought Indices Analysis*. Final report. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2017h. *Development of a monitoring and reporting system on the status of climate change impacts and adaptation in the Lower Mekong Basin: indicator cards and baseline assessment*. Technical Report. Mekong River Commission, Vientiane, Lao PDR.

MRC, 2017x. *Analysis of historical trends, variability and changes in hydroclimatic conditions for the Lower Mekong Basin*. Mekong River Commission, Vientiane, Lao PDR.

Ngor, P.B., Chheng, P. and So, N. 2015. Declines in catches of some large and medium-sized species in Tonle Sap River. *Catch and Culture*, 21: 4-7.

Nguyen, A.L., Dang, V.H., Bosma, R.H., Verreth, J.A.J., Leemans, R. and Silva, S.S.D. 2014. Simulated Impacts of Climate Change on Current Farming Locations of Striped Catfish (*Pangasianodon hypophthalmus*; Sauvage) in the Mekong Delta, Vietnam. *AMBIO*, 43: 1059–1068.

Nicholls, R.J., Hanson, S. Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Château, J. and Muir-Wood, R. 2008. *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes.* OECD Environment Working Papers No. 1. University of Southampton, United Kingdom: OECD Publishing.

OECD/Food and Agriculture Organization of the United Nations, 2015. *OECD-FAO Agricultural Outlook 2015*. OECD Publishing, Paris, France.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., *et al.* 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth. *Bioscience*, 51(11): 933-938.

Park, D-S.R., Ho, C-H. and Kim, J-H. 2014. The growing threat of intense tropical cyclones to East Asia over the period 1977-2010. *Environmental Research Letters*, 9: 1-7.

Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge, UK, 976.

Randall, D.A., Wood, R.A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., Kattsov, V., Pitman, A., Shukla, J., Srinivasan, J., Stouffer, R.J., Sumi, A. and Taylor, K.E. 2007. Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Eds: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L.), Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Regmi, M.B., Hanaoka, S. 2011. A survey on impacts of climate change on road transport infrastructure and adaptation strategies in Asia. *Environmental Economics and Policy Studies*, 13: 21 – 41.

Ringler, C., 2001. *Optimal water allocation in the Mekong River Basin*. ZEF – Discussion Papers on Development Policy No.38. Bonn, Germany.

Stainforth, D.A., Allen, M.R., Tredger, E.R. and Smith, L.A. 2007. Confidence, uncertainty and decision-support relevance in climate predictions. *Philosophical Transactions of the Royal Society A,* 365: 2145-2161.

Stephens, E.M., Edwards, T.L. and Demeritt, D. 2012. Communicating probabilistic information from climate model ensembles—lessons from numerical weather prediction. *WIREs Climate Change 2012,* 3: 409–426.

Stibig, H-J. 1997. *Interpretation and Delineation from Satellite Images, Tehnical Notes 2 of the Forest Cover Monitoring Project: a Co-operation project between the Mekong River Commission (MRC) and the Gesellschaft fuer Technische Zusammenarbeit (GTZ).* \Mekong River Commission, Vientiane, Lao PDR.

Talberth, J. 2015. *Valuing ecosystem services in the Lower Mekong Basin: country reports for* [separately] *Cambodia, Lao PDR, Thailand and Viet Nam*. Development Alternatives Inc. and World Resources Institute for the USAID Mekong Adaptation and Reslience to Climate Change Project, Washington D.C. United States.

Talberth, J. and Reytar, K. 2014. *Climate Change in the Lower Mekong Basin: an analysis of economic values at risk.*USAID Mekong Adaptation and Resilience to Climate Change programme.

Thang, N.V., Hieu, N.T., Thuc, T., Thanh, H.P.T., Lan, N.T. and Thang, V.V. 2010. *Climate change and its impact in Vietnam*. Ha Noi.

Thuc, T., 2012. *Climate Change Scenarios for Viet Nam*.

Trieu, T.T.N. and Phong, N.T. 2014. The impact of climate change on salinity intrusion and Pangasius (*Pangasianodon Hypophthalmus*) farming in the Mekong Delta, Vietnam. *Aquaculture International*, 23: 523–534

USAID, 2013. *USAID 2013 Mekong ARCC climate change impact and adaptation study for the Lower Mekong Basin: Main Report*. Prepared for the United States Agency for International Development by ICEM – International Centre for Environmental Management. Bangkok: USAID Mekong ARCC Project. Available online at: www.mekongarcc.net/resource.

WFP, 2007. *Lao PDR: Comprehensive Food Security & Vulnerability Analysis*. World Food Programme. Available online at: http://www.wfp.org/content/lao-pdr-comprehensive-food-security-and-vulnerability-analysis-2007.

World Bank, 2010. *Vietnam: economics of climate change adaptation*. World Bank, Washington.

World Bank, 2012. *Hidden harvest: The global contribution of capture fisheries.* World Bank, Washington.

Wu, M-C., Yeung, K-H. and Chang, W-L. 2006. Trends in western north Pacific tropical cyclone intensity. *Earth and Space Science News*, 87(48): 537-538.

WWF, 2013. *The economic value of ecosystem services in the Mekong Basin: what we know and what we need to know*. World Wide Fund for Nature, Gland, Switzerland.

WWF, 2015. *Terrestrial Ecoregions:* http://www.worldwildlife.org/biome-categories/terrestrial-ecoregions [Accessed 15 December 2015]. World Wide Fund for Nature, Gland, Switzerland

Xue, Z., Liu, J.P. and Ge, Q.A. 2011. Changes in hydrology and sediment delivery of the Mekong River in the last 50 years: connection to damming, monsoon, and ENSO. *Earth Surface Processes and Landforms*, 36: 296–308.

Yokoyama, S., Tanaka, K. and Phalakhone, K. 2006 Forest Policy and Swidden Agriculture in Laos. In: *Proceedings of the NIE-SEAGA: Sustainability and Southeast Asia, 2006*. Singapore.

Yu, N., Zheng, D., Ding, X., and Huang, C., 2002, *Sea level change in Shanghai from tide gauge records*, in: Huang, C., and Qian, Z., (eds.), Proceedings of the Fourth Workshop of the Asia-Pacific Space Geodynamics Program, Shanghai, China, May 15–18, 2001: Shanghai Scientific and Technical Publishers.

Zomer, R.J., Trabucco, A., Metzger, M.J., Wang, M. and Oli, K.P. 2014. Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India, Nepal. *Climatic Change*, pp. 445–460.

Zomer, R.J., Xu, J., Wang, M., Trabucco, A. and Li, Z. 2015a. Projected impact of climate change on the effectiveness of the existing protected area network for biodiversity conservation within Yunnan Province, China. *Biological Conservation*, 184: 335–345.

Zomer, R.J., Wang, M. and Xu, J. 2015b. *Projected Climate Change and Impact on Bioclimatic Conditions in Central and South-Central Asia* - ICRAF East and Central Asia Research Report. ICRAF Working Paper 187. World Agroforestry Centre East and Central Asia, Kunming, China 1–50.

Zomer, R.J. 2016. *Projected climate change and impact on bioclimatic conditions and terrestrial ecosystems of the Lower Mekong Basin*. Final Report to the Mekong River Commission: Environmental stratification and projected spatial shift of bioclimatic strata within the LMB by 2030 and 2060. 133 pp.

Appendix A

Proposed list of potentially suitable climate change and adaptation indicators

Table 1: Revised list of potentially suitable climate indicators (indicators 1-21)

	Indicator	Unit	Parameters used to calculate indicator
TEMPERATURE			
1	Highest max. daily temp. per year	°C	Daily maximum temperature
2	Lowest min. daily temp. per year	°C	Daily minimum temperature
3	Annual average of daily diurnal temp. range	°C	Daily maximum and minimum temperature
4	Number of hot days (Tmax > 35°C) per year	days	Daily maximum temperature (Tmax)
5	Number of cold days (Tmax < 35°C) per year	days	Daily maximum temperature (Tmax)
6	Number of hot nights (Tmin > 25°C) per year	days	Daily minimum temperature (Tmin)
7	Number of cold nights (Tmin < 25°C) per year	days	Daily minimum temperature (Tmin)
PRECIPITATION			
8	Total precip. per year	mm	Daily precipitation
9	1-day maximum precip. per year	mm	Daily precipitation
10	5-day maximum precip. per year	mm	Daily precipitation
11	Number of heavy precip. days (> 100 mm/day) per year	days	Daily precipitation
12	Maximum consecutive dry days (< 1 mm/day) per year	days	Daily precipitation
13	Maximum consecutive wet days (> 1 mm/day) per year	days	Daily precipitation
14	Annual Standardised Precipitation Index (SPI)	SPI	Normalised annual precipitation totals
15	Generalised Monsoon Index (GMI)	%	Monthly precipitation totals (June-Sept)
OTHER METEOROLOGICAL INDICATORS			
16	Total evaporation per year	mm	Daily evaporation
17	Annual average of daily relative humidity	%	Daily relative humidity
18	Annual average of daily sunshine duration	hours	Daily sunshine duration
STORMS AND TYPHOONS			
19	Number of storms or typhoons that impact LMB per year (and 5-year moving average)	Count (i.e. no unit)	Joint Typhoon Warning Centre (JTWC) best track data[4].
20	Annual average storm/typhoon intensity	km/h	Maximum wind speed of each storm[5]
21	Annual Accumulated Cyclone Energy (ACE) index	10^4 knots^2	Wind speed measured at 6-hour intervals

[4] Done for all storms combined and for each storm category: Tropical Storms (TS), Severe Tropical Storms (STS), Typhoons (TY), Super Typhoons (ST), Tropical Cyclones (TC).
[5] 5. Done for all storms combined and for each storm category.

Table 2: Revised list of potentially suitable impact indicators (indicators 22-57)

Indicators	Unit	Parameters used to define indicators
Water quantity		
22. Human water stress index	-	Water supply demand and water availability
23. Environmental water stress index	-	Environmental water requirement and water availability
24. Agriculture water stress index	-	Crop water demand and water availability
25. River water level/flow (min./max.)	$m/m^3/s$	Based on most robust/indicative water level/flow data (e.g. 1, 7, 10, 15, 30-day)
Water quality		
26. Water quality index for human health	-	Climate-sensitive parameters with data showing changes attributable to climate change to be selected for each indicator from list in Table 4
27. Water quality index for protection of aquatic life	-	
28. Water quality index for agriculture	-	
Land		
29. Soil moisture index	%	Active or passive microwave
30. Total erosion area	ha	River bank and coastal erosion area
Biodiversity and ecosystem		
31. Number/distribution of threatened and endangered terrestrial species	No./range	Threatened and endangered species
32. Number/distribution of threatened and endangered aquatic species	No./range	Threatened and endangered species
33. Total wetland cover area	ha	Wetland area
Socio-economic		
34. Number/percentage of population affected by high temperatures	No./%	Total population and number of people (e.g. very young, sick and elderly) affected by high temperatures (T max. day >42ºC/T max. night >32ºC)
35. Number/percentage of population killed by heat stress	No./%	Total population and number of people killed by heat stress
36. Number/percentage of population affected by vector-borne diseases	No./%	Total population and number of people affected by vector-borne diseases
37. Number/percentage of population killed by vector-borne diseases	No./%	Total population and number of people killed by vector-borne diseases
Agriculture		
38. Crop yield (rice, maize, sugarcane and cassava)	t/ha	Crop production
39. Crop harvesting area (rice, maize, sugarcane and cassava)	ha	Total crop area
Fisheries and aquaculture		
40. Fish catch per unit effort	kg/hr	Weight of catch per hour spent fishing
41. Fisheries and aquaculture production	t/yr	Fisheries and aquaculture production
Food security		
42. Food production	t/yr	Production from agriculture, fisheries and aquaculture
Energy security		
43. Hydropower energy production	GWh/yr	Hydropower energy production
Flood damage		
44. Total flooded area	ha	Flooded area
45. Total cost of flood damage	$US/yr	Cost of flood damage
46. Percentage loss of agriculture production to total cost of flood damage	%	Total cost of flood damage and total cost of agriculture production loss
47. Percentage loss of fisheries and aquaculture production to total cost of flood damage	%	Total cost of flood damage and total cost of fisheries and aquaculture production loss
48. Percentage loss of property to total cost of flood damage	%	Total cost of flood damage and total cost of property loss
49. Number of vulnerable people exposed to flood risk	No.	Number of people below national poverty line living in flood-prone areas
50. Number of people killed by floods	No.	Number of people killed by floods
Drought damage		
51. Total drought area	ha	Drought area
52. Total cost of drought damage	$US/yr	Cost of drought damage
53. Percentage loss of agriculture production to total cost of drought damage	%	Total cost of drought damage and total cost of agriculture production loss
54. Percentage loss of fisheries and aquaculture production to total cost of drought damage	%	Total cost of drought damage and total cost of fisheries and aquaculture production loss
55. Percentage loss of property to total cost of drought damage	%	Total cost of drought damage and total cost of property loss
56. Number of vulnerable people exposed to drought risk	No.	Number of people below national poverty line living in drought-prone areas
57. Number of people killed by drought	No.	Number of people killed by drought

Table 3: Revised list of potentially suitable adaptation indicators (indicators 58-66)

Indicators	Unit	Parameters used to define indicators
Policy and institutional response		
58. Level of mainstreaming climate change adaptation into policies and strategies	No.	Number of endorsed policies and strategies at regional, national, provincial and sector levels
59. Regional budget for climate change adaptation	$US	Regional line budgets
60. Percentage of national budget for climate change adaptation	%	National line budgets and total budget
61. Percentage of employment in climate-related sectors	%	Total employment and number employed in climate-related sectors
Adaptation response		
62. Total conservation area	ha	National conservation area
63. Total irrigation area	ha	Irrigation area
64. Total water storage in reservoirs	km^3	Storage volume of surface water reservoirs
65. Coverage of disaster warning systems	km^2	
66. Total mangrove area	ha	Mangrove area