Session 2.2: Land, Water, and Climate Change

WATER FOR FOOD AND ENERGY IN THE GMS: ISSUES AND CHALLENGES TO 2020

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1. Introduction

The countries of the Greater Mekong Subregion (GMS) are experiencing rapid economic and population growth, with concomitant increases in demand for food and energy. The traditional rice-fish livelihood systems of the region, with their dependence on the annual flood pulse and natural aquatic ecosystems, still play an important role but are increasingly giving way to urban and industrial development. Demand for energy from hydropower, and irrigation for intensive commercial food production to meet the needs of urban populations are reshaping the way that water resources are used.

The region faces difficult decisions about how water resources will be managed to balance the requirements of different sectors. The three major water sectors in the GMS (hydropower, agriculture, and fisheries) are inextricably interlinked, and management responses must take account of the interactions and inherent trade-offs between sectors to offset potential conflicts and capitalize on synergies. This paper explores the nexus between water, food, and energy in the GMS and the changing understanding of the issues and challenges driving water resource development in the next 10 years.

2. Water Resources in the GMS – Status and Trends

2.1. Water and Agriculture

Agriculture is by far the largest consumer of water in all GMS countries, estimated to account for 68% (in the People's Republic of China [PRC] and Viet Nam) to 98% (in Cambodia) of total withdrawals (WRI, 2009; Table 1). Despite this, the proportion of irrigated land in GMS countries is relatively low by world standards (ranging from 7% of total cropland in Cambodia to 31% in Viet Nam [World Bank, 2009a]), the availability of renewable freshwater in most countries is high and rainfed agriculture dominates production. While the overall availability of water resources in the GMS may not be affected significantly by climate change, agriculture is vulnerable to local climatic variability, with significant risk from both floods and droughts even under current climate conditions. Increasing and safeguarding production will require improvements in water management in both rainfed and irrigated systems.

Table 1: Water and Agriculture Indicators for GMS Countries

	Unit	Cambodia	PRC	Lao PDR	Myanmar	Thailand	Viet Nam
GDP from agriculture (%) (2008)		32.5	11.3	32.1	46.7	11.6	22.1
Agricultural population (%) (2006)		68	64	76	69	45	65
Arable land 2007	km^2	38,000	1,406,300	11,700	105,770	152,000	63,500
Arable land per capita (2007)	ha/person	0.26	0.11	0.20	0.22	0.24	0.07
Area equipped for irrigation as % of arable land 2007		8	41	26	21	33	47
Internal renewable water resource	km^3/year	121	2,812	190	881	210	366
Total actual renewable water resource	km^3/year	476	2,830	334	1,046	410	891
Per capita water resources, m^3/person	2007	33,537	2,130	57,914	21,613	6,462	10,338
Total annual water withdrawal	km^3/year	4.08	630	3.00	33.20	87.10	71.40
Per capita annual water withdrawals	m^3/capita/year	308	486	555	711	1,412	877
% withdrawn for agriculture		98	68	90	98	95	68
% withdrawn for industry		1	26	6	1	2	24
% withdrawn for domestic use		2	7	4	1	2	8

km = kilometer
m – meter
Source: Adapted from Johnston *et al.* (2010).

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Agriculture in the GMS is in transition from traditional subsistence systems to modern commercial production of a wide range of commodities for both domestic consumption and export, with significant implications for water demand and water quality. Agricultural production in the GMS over the last 20 years has seen steady increases across all subsectors and all countries. Production in major commodity groups has more than doubled since 1990, outpacing the region's rapid population growth (FAOSTAT, 2009; see Johnston *et al*., 2010 for a more detailed discussion of agricultural trends). Most of this remarkable increase has come from intensification and increases in yield, rather than expansion in agricultural area, which grew by less than 5% over the same period (FAOSTAT, 2009). Crop yield increases have resulted from the range of new technologies and approaches that underpinned the green revolution (IRRI, 2008): uptake of improved varieties, increasing use of fertilizers, improved farming practices, and the expansion and more efficient use of irrigation.

All national governments in the GMS see expansion of irrigation as an important priority, both to increase production and to reduce risk from climate change. FAO statistics indicate that irrigated areas in the region (excluding Yunnan Province, PRC) increased by at least 1 million hectares (ha) between 1990 and 2003 (World Bank, 2009a), but national figures suggest an even larger increase. UNDP (2006) reported that government programs in Myanmar doubled the area under irrigation over the last 20 years to 1.4 million ha; and the Cambodian Government estimates that over 0.73 million ha of land now have irrigation compared to less than 0.25 m ha in 1990 (MAFF and MOWRAM, 2007; FAOSTAT, 2009). In other words, while irrigated agriculture is not as dominant here as in other parts of Asia, the irrigated area is expanding relatively rapidly.

The largest irrigated areas are found in the mega-deltas and low-lying floodplains of the Red, Mekong, Chao Phraya, and Irrawaddy rivers, the "rice-bowls" of the region. Although they constitute only 10% of total land area, they produced almost 50 million (metric) tons of rice in 2005, half of the region's production (excluding Yunnan) and around 8% of the global crop (FAOSTAT, 2009; national government statistics). In these areas, complex systems of dykes, levees, and canals are also used to divert and retain the floodwater of the monsoon. Only the Red and Chao Phraya deltas have significant upstream storage to regulate supply (Water Resources e-Atlas, 2003). The importance of production from traditional wet season (May to October) rice cultivation with supplementary irrigation is increasingly being diminished by fully or partially irrigated crops before and after the wet season, taking advantage of higher solar radiation and lower flood risk. For example, in the Mekong Delta, the contribution of (long duration) wet season rice crop has declined to only 10% of total annual, which is now dominated by two irrigated crops in winter-spring and summer-autumn (VN GSO, 2009). This trend has produced significant increases in both yield and total production, but places water resources under stress.

The extent and success of irrigation development in areas upstream of the deltas has been more variable. In Thailand, there has been substantial investment in irrigation storage for the inland plains, with large multi-purpose storages in both the Chao Phraya Basin and the Isan plateau, and thousands of small dams and reservoirs servicing small to medium schemes (Molle, 2004). Despite this, the area of dry season (November to April) irrigated crops planted is significantly lower than the total irrigable area. Similarly, in Cambodia the majority of irrigation schemes in the inland plains around Tonle Sap are used mainly for supplementary irrigation of wet season rice; only 13% of the total rice crop is grown in the dry season, most of this on the Mekong floodplains in the south (MAFF, 2009b). In Myanmar, programs begun in the 1980s have expanded irrigation to cover approximately 25% of crop area, with significant development in the inland plains, but irrigation intensity is generally suboptimal; for example, the Sedawgyi dam project runs at 61% of its total command area, with the remaining area utilized as rainfed (UNDP, 2006; FAO, 2008). Low uptake of dry season irrigation in the region is attributed to a mixture of factors, including inappropriate infrastructure designed to manage floods for wet season rice production and not dry season crops, a lack of farmer knowledge of dry season cultivation techniques, other labor opportunities in the dry season (seasonal migration to the cities), and operating and maintenance problems. Small- to medium-scale irrigation, mainly pumped directly from rivers, is common in the intensively farmed upland river valleys of northern Thailand and Yunnan for high-value horticultural produce and other cash crops. Groundwater irrigation in the Central Highlands of Viet Nam and the Bolavens Plateau of the Lao People's Democratic Republic (Lao PDR) has allowed establishment of large areas of coffee, but overexploitation has threatened the sustainability of groundwater resources in some areas.

Overall, withdrawals are only a small fraction of total renewable resources (maximum of 22% in Thailand; Table

1), but demand for agricultural water is increasing and the strongly seasonal patterns of rainfall and irrigation demand mean that seasonal shortages are common. Pech and Sunada (2008) estimate that more than 80% of flows from upstream are extracted for irrigation in the Mekong Delta during the critical dry season months of March - April, resulting in local shortages and intrusion of seawater. Both the Chao Phraya and the Red rivers are essentially "closed" basins (Molle, 2004), and further development of irrigation will result in water transfers from other sectors, whether planned or not. In the Isan Plateau in northeastern Thailand, seasonal water shortages have led to conflict between urban and agricultural users in the dry season (MRC-TNMC, 2004).

The current trend toward establishment of large commercial plantations (for rubber, oil palm, cassava, coffee, and other crops) is also likely to impact on agricultural water demand. Concessions to develop plantations have been granted over large areas of land, particularly in Cambodia and the Lao PDR (MPI, 2008; Rutherford *et al*., 2008; MAFF, 2009a). It is not clear what the ultimate impact of these plantations will be on water availability and demand. Most of the current development is rainfed, but at least some of the investment deals have included funding to build irrigation infrastructure; for example, the Kuwaiti loan of $546 million to Cambodia to build an irrigation dam on the Stung Sen (Economist, 2008); and Chinese loans to Myanmar to construct joint hydropower and irrigation infrastructure (International Rivers, 2009).

Widespread conversion of forest or grassland to agriculture may have significant impacts on run-off and water use, though these may operate in different directions at different scales. Clearing generally increases run-off, while reforestation (or establishment of tree crops) has been demonstrated to decrease overall water yield from catchments by up to 30% per year in tropical southern PRC (Sun *et al*., 2006). Lacombe *et al*. (2010) have demonstrated measurable increases and decreases in runoff at large catchment scale due to deforestation and reforestation respectively.

Water quality in most of the region is generally not limiting for human use (MRC, 2010) but serious water quality issues associated with high population density and inadequate treatment of sewage and industrial effluent downstream of cities occur in all the major deltas. Fertilizer, pesticide and herbicide inputs from agriculture are significant in the Chao Phraya, Red and Mekong deltas; some aquaculture practices are highly polluting; and intrusion of seawater in the dry season and acid sulphate drainage from poorly managed pyritic soils affects large areas in all the deltas (MRC-VNMC, 2004). Levels of agricultural pollutants in most other areas are presently low, although high concentrations may occur in some localized cases. Further intensification of agriculture will increase the threat of non-point source pollution. Irrigation-induced salinity affects parts of northeastern Thailand and the central Lao PDR, exacerbated by saline groundwater (Eastham *et al*., 2008).

2.2. Water, Fisheries, and Aquatic Ecosystems

The region contains extensive and diverse wetlands ecosystems, comprising riverine floodplains, fresh- and brackishwater deltaic wetlands and major lake systems, including the Great Lake (Tonle Sap) system (Southeast Asia's largest freshwater lake), Lake Inle in Myanmar, and large upland lakes in Yunnan. Traditionally, wetlands have played an important role in livelihoods, providing fish and other aquatic animals, as well as reeds and a range of food and medicinal plants (MRC, 2010).

Food production in the GMS has a high degree of dependence on freshwater ecosystems, which must be seen as an integral part of agricultural production systems. Average per capita fish consumption is estimated at 23–45 kg/capita/year, and fish in some areas provide between 50% and 80% of total protein (Hortle *et al*., 2004; Hortle, 2007; Soe, 2008). Studies on the socioeconomics of fish production in the GMS indicate a very high level of participation in fishing, and emphasize the importance of the inland capture fishery for small-scale livelihoods and food security (Phan *et al*., 2003; van Zalinge *et al*., 2004). Fisheries also make an important contribution to the regional economy. Estimates of the total value of the Mekong fishery alone are as high as $3 billion per year (Barlow *et al*., 2008; Friend, 2009). The fisheries industry accounts for between 4% (Thailand) and 11% (Cambodia) of GDP (Sugiyama *et al*., 2004; Soe, 2008); in Cambodia, this places it ahead of rice production (Hortle *et al*., 2004).

There is a common perception that the region's inland fish catch is declining, and there is a high degree of concern regarding the sustainability of the capture fishery. The perception of decline is related mainly to a significant (40%–50%) decrease in catch per fisher as the total population and the number of people engaged in fishing has increased (Baran, 2005). Official statistics indicate that the overall freshwater catch in the region increased between 1990 and 2000 (FAOSTAT, 2009), and there

is no evidence of a decline since then. Concerns about sustainability remain, as there is evidence that large and medium migratory species have declined, and the average size of fish has also declined, a pattern typical of overfishing (Hortle *et al*., 2004). There have been dramatic increases in both freshwater and brackishwater aquaculture production since the turn of this decade, with official increases of over 300% in brackishwater and over 500% in freshwater systems (FAOSTAT, 2009; Department of Fisheries Thailand, 2009). However, in the case of the Mekong, aquaculture represents less than 10% of total production, and while it can complement the capture fishery it cannot replace it in terms of food security (ICEM, 2010). In addition, aquaculture depends heavily on the capture fishery for stocks and feed.

Changes to river flow regimes, loss of habitat and disruption of migratory paths pose significant risks to inland fisheries in the GMS. The fish catch is strongly dependent on the extent, duration, and timing of flooding, and access to productive floodplain and wetland habitats for feeding (van Zalinge *et al*., 2004; Krittasudthacheewa and Apirumanekul, 2008). Increasing areas of floodplain are being cleared or converted to agricultural use; for example, the area of flooded forest around Tonle Sap fell from over 1 million ha in the early 1970s to 0.45 million ha by 1997 (Evans *et al*., 2004). Infrastructure, such as dykes and roads, disrupt access by fish to the floodplain for spawning and feeding. Proposed development of large-scale hydropower facilities will modify river flows and flooding regimes and block migration routes.

2.3. Hydropower

The GMS has estimated potential hydropower resources of over 200,000 megawatts (MW). However, in the near future only 6,000 MW will be developed and over the long run approximately 26,000 MW is foreseen as the maximum installed capacity. Demand for energy within the region is growing rapidly, and all governments are considering major hydropower developments to meet part of that demand. A review of hydropower in the GMS (King *et al*., 2006) compiled an inventory of 82 projects existing or under construction and a further 179 planned and proposed projects. Figure 1 indicates the main planned developments within each of the major basins in the region. Hydropower development is considered as a relatively cheap, independent solution for energy demand, and also contributes less GHG emissions than alternatives such as charcoal, oil, and biofuel. However, existing and proposed major hydropower development will result in changes to flow regimes and river ecology with significant implications for both agriculture and fisheries.

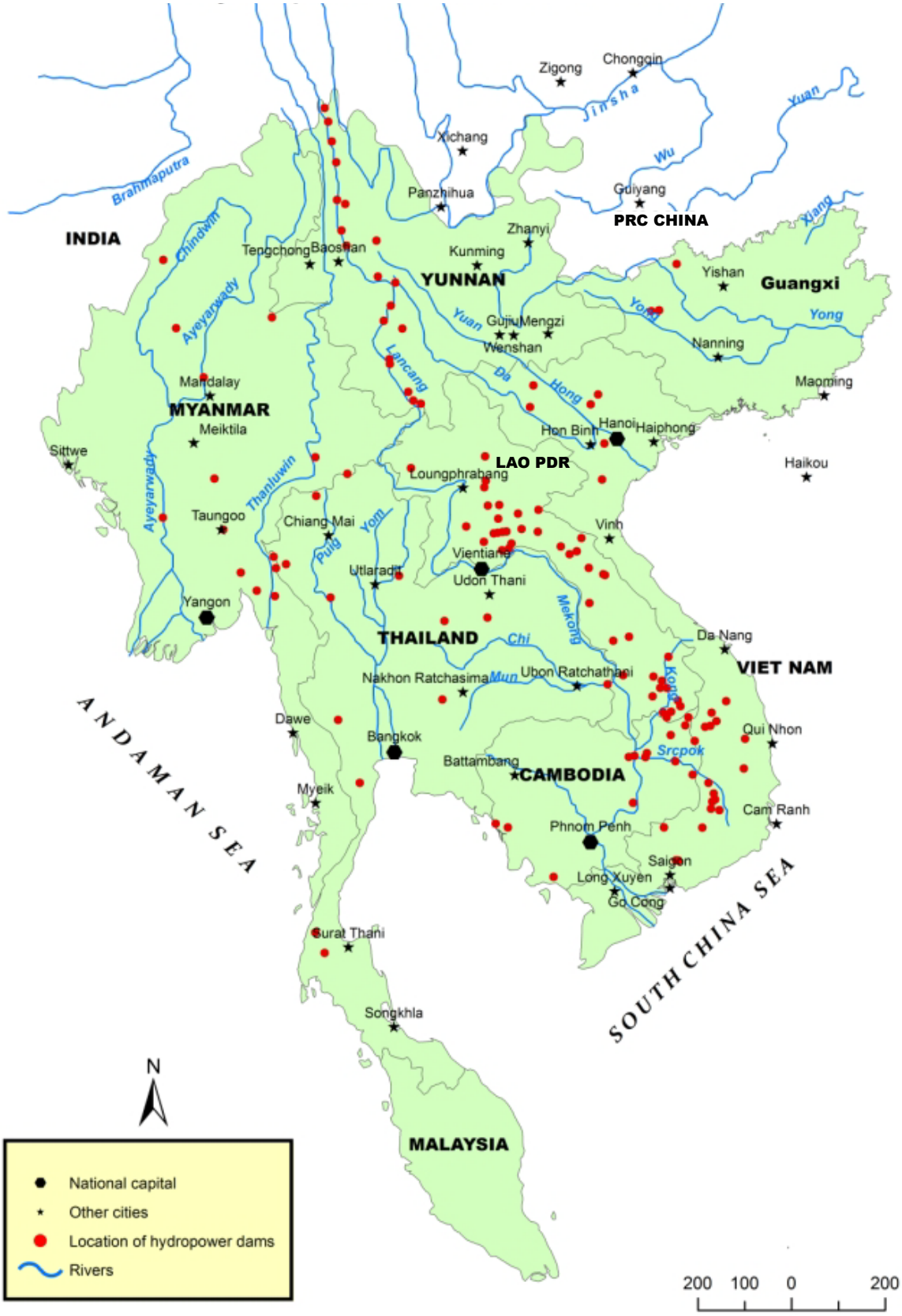
While mainstream developments in the lower Mekong are in most cases proposing run-of-the-river facilities, many of the envisioned tributary projects include considerable storage and will drive significant and immediate change in seasonal distribution of flows (MRC, 2010). For example, current development in the Mekong provides around 10 km^3 storage (2.5% of mean annual runoff [MAR]); under a "definite future" scenario, MRC (2011) estimate this will increase to 46 km^3 and under a range of 20-year "full development" scenarios to more than 73 km^3 (15% of MAR).

Assessment of the hydrological impacts of the "definite future" scenario predicts an increase in dry season discharge of around 20% at Kratie, with accompanying reduction in wet season flows averaging 7%. Under the 20-year scenarios, dry season flows would be expected to increase 30%–100% above baseline conditions; and wet season flows to decrease by 4%–15%, depending on location on the river and the details of the scenarios considered.

The projected increase in dry season discharge is larger than projected irrigation demands from all Lower Mekong countries and could provide significant opportunities for irrigation development and for mitigation of current dry season shortages and saline intrusion in the Delta. There are concerns that at lower scales the availability of increased water supply from the hydropower dams may not coincide with increased irrigation demands. One such area of concern is the Vientiane Plain, but recent research results demonstrate that the increase in dry season flows will be greater than the likely demand.

Proposed dams on the Mekong mainstream (ICEM, 2010), including the currently controversial Xayaburi dam in the Lao PDR, are run-of-river dams with only small storages, but will form a barrier to fish migration. Blockage of migration paths by dams has serious impacts on recruitment and spawning (Thanh *et al*., 2004; van Zalinge *et al*., 2004). A high proportion of fish species in Southeast Asian Rivers are migratory, with seasonal movements over large distances to access spawning and feeding grounds (Baran, 2006). Dugan (2008) reports that up to 70% of the Mekong fishery depends on long-distance migrant species. Halls and Kshytriya (2009) investigated the impact of barrier effects of Mekong mainstream dams on fish populations using population dynamic models,

Figure 1: Current and proposed hydropower development in the Greater Mekong Subregion
(Johnston *et al.*, 2010; data from ADB, 2009b)



and concluded that structures would need to pass at least 60%– 87% of upstream migrating adults to maintain viable exploited populations. Passage success rates at this level have never been achieved elsewhere; and even higher levels were needed for larger species, or if multiple dams were included in the analysis. Mainstream dams thus pose a significant threat to the viability of migratory fisheries (Ferguson *et al*., 2010), and it is essential that these impacts—and their economic and social consequences—are taken into account in feasibility and impact studies.

Large dams trap sediment carried by rivers and can significantly reduce suspended sediment load and delivery of sediment to downstream areas. Removal of sediments results in geomorphological changes in the river (increased bed scour, channel and bank erosion) and decreased ecosystem productivity in the floodplain (because nutrients are carried with sediments). Kummu and Varis (2007) estimated that the major Chinese reservoirs on the upper Mekong (Lancang) will have sediment trapping efficiencies between 66% and 92%, with large potential impacts for downstream areas.

2.4. Climate Change

Anticipated climate changes in the GMS to 2050 (Johnston *et al*, 2010; TKK and SEA-START, 2009; Kistin and McCornick, 2010; Lacombe *et al*., 2011) can be summarized as:

- *Temperature* will increase by 0.02–0.03°C per year across the entire region in both warm (March to October) and cool (November to February) season, with higher rates of warming in Yunnan and northern Myanmar, especially during the cool season. Higher temperatures will increase evapotranspiration, increasing the water demand of crops and pastures in both rainfed and irrigated systems. Irrigation demand in semi-arid regions of Asia is estimated to increase by 10% for each 1°C temperature rise, but this expected to be less in the GMS (Fischer *et al*., 2002).
- *Rainfall.* Projected changes in rainfall across the region vary from decreases of a few millimeters (mm) per year to increases of up 30 mm with a high degree of uncertainty. Some (small) seasonal shift in rainfall, with drier dry seasons, and in some studies shorter, more intense wet seasons will occur, so that even if total annual rainfall does not change significantly, it is possible that the availability of water for agriculture may change, with increases in the incidence of both droughts and floods.
- *Sea level* is expected to rise 33 cm by 2050 (MONRE, 2008) in addition to observed rise of 20 cm over the last 50 years (Hien, 2008)
- *Typhoons.* Increase in sea surface temperature may increase the intensity and incidence of typhoons during El Ninõ years (MRC, 2009).
- *Glacier melt.* The impact of the glacier melting is negligible in the two main catchments of the GMS (Mekong and Irrawaddy). The situation may slightly differ in the Salween catchment where the ice melting contribution to total runoff is higher, but the population that would potentially be impacted by such changes represents only 2% of the total population of the GMS (Johnston *et al*., 2010). The effects of temperature rise in the upper Mekong Basin will induce earlier snow melting, thus causing higher flow in springtime (April-May) and lower flow in Summer (July-August) (Kingston *et al*., 2011; and Hoanh *et al*., 2010).

Sea level rise is a significant threat in the GMS, since low-lying deltas host five of the region's major cities and a large area of highly productive land. Sea level rise in the deltas is exacerbated by land subsidence due to groundwater extraction and sediment loss. Syvitski *et al*. (2009) report relative sea level rises of 6 mm per year in the Mekong Delta and, due in part to subsistence caused by groundwater over-abstraction, higher levels in the Chao Phraya Delta (Wada *et al*., 2010), much higher than the global mean of 1.7 mm per year over the last century. For an extreme scenario of 1 meter rise in sea level, Dasgupta *et al*. (2007) estimate that more than 5% of Viet Nam's total land area and 10% of its population would be affected, with 5,000 km^2 of the Red River Delta and 15,000–20,000 km^2 of the Mekong Delta being flooded. The Red, Chao Phraya and Irrawaddy are steeper deltas, and so less prone to sea level rise; Dasgupta *et al*. (2007) estimate that a 1 meter rise in sea-level would have smaller but still significant impacts, affecting 1%–2% of both total land area and population.

These conclusions are only from a simple comparison of sea level with ground elevation (Digital Terrain Model) without considering the hydrodynamics in the river system influenced by tide in the sea. Currently many locations in the Mekong Delta are lower than mean sea level but are not inundated because of river banks, and because there is insufficient time for the seawater to reach some locations. That said, and while the more severe impacts of sea level rise will not be felt until after 2050, it is essential to take longer-term impacts into consideration in planning and investment.

To date, only increases in temperature and sea level have been observed. Analysis of historical rainfall records indicates a high degree of variability, but no trend in either overall amount or seasonality of rainfall. This contrasts with the widespread perception, reflected in published reports (e.g., ADB, 2009a; WWF, 2009), that climate change is already being felt in the region as increases in the incidence and severity of extreme climate events. This perception is a result of confounding climate change with climate variability (or sometimes even with land-use change). For example, ADB (2009a) quotes Mekong floods in 2000 and droughts in the Lao PDR and Viet Nam in 1997 and 1998 as examples of extreme events attributed to climate change, but there is no convincing evidence that these events are outside of the range of normal climate variability, or that the frequency of such events has increased, at least in the mainland Southeast Asia (MRC, 2005; Johnston *et al*., 2010). In the Mekong Delta, the reported increase in flood damage can be attributed to demographic and land-use changes, as increasing population resulted in settlement of areas previously not used precisely because of their vulnerability to floods (Lacombe, *et al*., 2011). However, the rise in carbon dioxide emission during 2000–2007 was higher than levels in the worst-case scenario analyzed by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007), and global warming may accelerate much more quickly than current models indicate (GCP, 2008). Global studies (IPCC, 2007) suggest that temperature rise may become non-linear and much more rapid. Longer-term impacts of climate change may be correspondingly much more severe (ADB, 2009a).

Given the high degree of uncertainty around projections of rainfall and runoff, it is counterproductive to use them as the basis for adaptation planning until more consistent estimates are available. It is more useful to characterize likely change as an increase in the variability and uncertainty of water availability and to take a "no regrets" approach to water management, with actions to improve water-use productivity, improve access to on-farm and off-farm storage, and reduce water-related risks.

2.5. Other Drivers of Change

A combination of population growth and rising living standards is posing a new set of challenges in meeting future food demand in the GMS, and economic development is placing increasing pressure on land and water resources. Global markets are driving changes in agricultural production to meet export demands, and have opened up external sources of capital for investment in agriculture and infrastructure. The PRC's economic growth and re-emergence as a major trading partner is placing an ever-increasing demand on the natural resources of the region (Rutherford *et al*., 2008). Increased energy requirements are driving large hydropower developments, which will impact on freshwater ecosystems and water availability for agriculture. All these trends have implications for water management, but two forces are currently reshaping water and land management in the GMS at an unprecedented rate: population growth and foreign investment and trade.

The population in the GMS is projected to grow from its current level of 275 million to over 340 million by 2050 (World Bank, 2009a; World Gazeteer, 2009). Based simply on population growth, if no new land is brought into production, a 25% increase in average per hectare productivity will be needed simply to maintain current levels of per capita food production. This could only be achieved with significant increases in irrigation, placing heavy additional demands on water resources. Alternatively, to hold the current ratio of agricultural land per capita constant would require an additional 7.2 million ha of arable land—again, inducing large increase in water demand. Such increases in agricultural water demand are likely to come at the expense of flows for the environment, and will place significant pressure on ecosystems and biodiversity.

Changes in diet and globalization of food markets mean that the picture is much more complex. As incomes increase, there is a general trend common across the world to more diversified diets with a higher proportion of food from animal sources and high value fish, a shift from cereals to non-cereals, and an increase in consumption of high-value foods, such as fruit, sugar, and edible oils (Pingali, 2004). These trends are observed across Southeast Asia, although cultural and regional differences are pronounced; for example, Thailand consumes significantly less animal products than does the PRC, even with much higher GDP. Changes in dietary preferences have significant implications for food production systems: a more meat-based diet requires a much higher level of resource inputs, including water (CA, 2007).

Agriculture in the GMS is transforming in response to global markets, directly through investment in agribusiness and indirectly, as export markets (particularly in the PRC) influence production trends. International demand for such commodities as rubber, cassava, sugarcane, corn, palm oil, cashews, coffee, pepper, and eucalyptus has driven a large shift in production,

with an increase in commercial plantations and contract cropping. Governments in Cambodia and the Lao PDR are promoting commercialization and industrialization of agriculture, and seeking private investment (foreign and domestic) to fund the transition. This has resulted in an upsurge of investment in plantation agriculture which is profoundly altering agricultural production, with a rapid rise in plantings of commercial (often non-food) crops such as rubber, oil palm, grains, and legumes for feed stocks.

Investment is also driving rapid expansion in the mining and energy sectors. Most activity in hydropower in the GMS is funded through foreign investment, except in Viet Nam and Yunnan, where domestic and government companies dominate. For example, in Cambodia and the Lao PDR, the PRC is currently involved in over 20 hydropower projects either as an investor or developer (Rutherford *et al*., 2008), with a large number of potential projects in the pipeline (King *et al*., 2006); International Rivers (2009) lists over 50 current and proposed hydropower projects in Myanmar funded or built by PRC companies. International investment has financed the development of large-scale mines in the region; for example, in the Lao PDR, the gold and copper mines at Phu Bia and Sepon (Australian/ Chinese investors), and coal mines in Xayabury (Thai investors).

Recently, extensive deposits of bauxite have been identified in northeastern Cambodia, the southern Lao PDR, and the Central Highlands of Viet Nam. Chinese, Vietnamese, and Australian companies, among others, have put forward proposals for large-scale extraction and processing. Development of these deposits, started in Viet Nam in 2009, could have significant impacts on water resources and the environment locally. In addition to water demand for mining and processing, and questions of disposal of the large volumes of "red muds" produced as wastes from processing bauxite, smelting of alumina requires enormous amounts of energy, and the viability of bauxite extraction may ultimately depend on concomitant development of hydropower as an energy source (Lazarus, 2009).

3. Discussion

Over the next 10–20 years, water resources will be shaped by a complex mixture of social., economic, and environmental factors. Some, like climate change and population growth, are cumulative while others, such as food prices, oil prices, financial crises, and political fluctuations, can have immediate and severe effects, but these effects fluctuate over time and tend to even out. Efficient use of water is fundamental to future food security and sustainable economic growth in the region.

The most controversial aspect of Mekong water management is the debate surrounding hydropower development. Potential impacts of hydropower development in the Mekong have been extensively reviewed by the Mekong River Commission (ICEM, 2010; MRC, 2011), and identify inherent trade-offs between hydropower development and fisheries production; potential benefits to irrigation through augmentation of dry season flows by hydropower dams; and significant variance in distribution of benefits between countries. These analyses highlight the difficult decisions that governments of the region will face. ICEM (2010) recommends a 10-year moratorium on mainstream dam development until impacts are better understood, given the importance of the Mekong system and the far-reaching and irreversible nature of the impacts of development. However, whether the impacts and alternatives can be fully understood in this time period, or whether it is too long of a delay for the benefits from the hydropower development to be realized is actively debated.

Instead, they recommend fast-tracking of tributary projects, since the impacts tend to be less extreme and more localized. Comparable studies have not been undertaken for the Salween and Irrawaddy, although large-scale developments are also proposed for these rivers.

Rising food prices and growing populations are driving renewed interest in investment in irrigation in Mekong countries (Hoanh *et al*., 2009); for example, the Cambodian Government has proposed over $1 billion in irrigation investments over the next 15 years (Thuon and Baskoti, 2010). Recent FAO studies found that large- to medium-scale public irrigation systems in Asia are generally performing well below their potential (Facon, 2007; Mukherji *et al*., 2009). Problems stem mainly from inappropriate design, operation, and maintenance. Given the high level of existing and planned investment in irrigation infrastructure, improving the performance of these systems must be a high priority. In many older irrigation systems in the GMS, water use is highly inefficient due to poor design of conveyance and application systems combined with a tendency to over-irrigation. Increased water-use efficiencies can be achieved through upgrade of distribution systems (channel lining, use of pipes) and the adoption of improved technologies, such as drip and

pivot irrigation, deficit irrigation, and the production of wet-dry (aerobic) rice.

Intensification of cropping systems through both full and supplementary irrigation in the dry season is needed to realize the full value of irrigation infrastructure. Many systems were initially designed around rice production (e.g., low drainage requirements, inflexible scheduling), making it difficult for farmers to diversify into higher value dry season crops. More flexible systems are needed to allow farmers greater control and autonomy of irrigation scheduling, thereby encouraging diversification of farming activities. In South Asia and the PRC there has been a massive shift to farmer managed small-scale pumping, even in areas where public irrigation previously dominated—the "atomization" of irrigation (Mukherji *et al*., 2009). There is evidence of a similar shift in Souteast Asia with a rapid increase in the number of small pumps installed in Viet Nam (>800,000 by 1999), Thailand (> 3 million by 1999), and more recently in Cambodia (120,000 in 2006) (MAFF, 2009b; Mukherji *et al*., 2009). Viability of pumped irrigation depends on energy costs; access to cheap electricity has been used as both an incentive and a control on overuse of pumping in India (Shah, 2009). Small-scale options and opportunities to adapt existing large-scale systems should be evaluated more thoroughly, including considering the energy requirements, before major new investments are made in large irrigation systems.

With rapid urbanization in GMS countries, the role of urban waste water within the agricultural sector in the region presents both a challenge and a potential opportunity to increase water-use efficiencies. This is an area that has not been promoted and one that holds significant implications for closing the nutrient cycle, reducing the costs associated with waste water treatment plants, and increasing water-use efficiencies.

Groundwater currently accounts for only a small proportion of irrigation in the GMS, but use is increasing. In many parts of Asia, there has been a substantial move to the use of groundwater for irrigation, often even where surface water is available (Mukherji *et al*., 2009; Shah, 2009) and this trend is also emerging within the GMS. Where conditions allow, managed aquifer recharge, storage, transfer, and recovery can be used to enhance water supplies, reduce the need for infrastructure, decrease evaporative losses, and improve groundwater quality though dilution. For example, flood waters can be pumped to aquifers for later recovery and use; and in highly connected floodplain systems, shallow aquifers can act as delivery systems for river water to the floodplain (NWC, 2009). Groundwater resources are thus of emerging importance, but little is known about their size and sustainability in the GMS. A comprehensive assessment of groundwater resources, use, and potential in the region is urgently needed, as the basis for management plans for the conjunctive use of surface and groundwater.

Despite the recent expansion of irrigation, rainfed agriculture dominates production in the GMS; the majority of the wet season rice crop is either rainfed or has only limited supplementary irrigation. Significant areas of the plains and uplands may never be irrigable because of topographic, hydrologic, or soil constraints; for example, FAO estimates that only 20% of total potential cropland in Cambodia is irrigable (MAFF and MOWRAM, 2007). Thus, a large proportion of cropland is likely to remain rainfed, and it is essential that water management options for rainfed agriculture are not neglected. Drought is the major risk in the plains and uplands, but rainfed production in the deltas and floodplains is prone to risks from both flood and drought. Technologies and practices for improving water management at the farm scale range from traditional techniques to modern innovations, including conservation agriculture, rainwater harvesting and storage, technologies for efficient application of water to plants (e.g., drip and trickle systems, clay pot sub-surface irrigation, bucket irrigation, direct application by hose) and breeding of crop varieties that are tolerant to drought and submergence (IWMI, 2006; CURE, 2009; IRRI, 2009).

The significance of freshwater fisheries and aquaculture to both food security and the economies of the GMS countries means that maintaining the health of freshwater ecosystems is a very important priority (Mainuddin *et al*., 2011). In addition to the valuable freshwater fishery, aquatic ecosystems also provide a range of ecosystem services—wetlands and lakes provide flood attenuation, ground water recharge, and water purification (Foley *et al*., 2005, CA, 2007); and wetlands are important agricultural systems for deepwater and recession rice (McCartney *et al*., 2011). Definition of the magnitude and timing of flows needed to maintain rivers, lakes, and wetlands in an ecologically acceptable condition (environmental flows) has been the subject of extensive debate and study internationally (Arthington *et al*., 2006, Richter *et al*., 2006). There is an urgent need to incorporate these approaches into water resources planning in the GMS before extensive developments are undertaken, to prevent degradation of fisheries and other environmental services observed in other parts of the world (World Commission on Dams, 2000b).

However, water infrastructure projects are an important component of national development plans and in this context, it is often difficult for decision makers to prioritize reserving flow for the environment over the more urgent requirements of income generation and poverty reduction. However, there is increasing recognition of the much broader economic and social importance of environmental flows, and of their role both in alleviating current poverty and in maintaining options for the future (SWH, 2009). To gain more policy traction in a development context, the definition of environmental flows needs to be broadened to explicitly include subsistence uses and be directly connected to the viability of freshwater fisheries.

4. Conclusions

In the next 10 years, the countries of the GMS face decisions about water resource development that will have far-reaching consequences. The relatively low level of water resource development in the region to date and high levels of dependence on natural aquatic ecosystems as a major source of food, means that there are both great opportunities and great risks. Increasing infrastructure and withdrawals will inevitably—and possibly irrevocably—change the way that river systems function. The dilemma facing the region's water resource managers is how to weigh benefits that rivers provide in their natural state (fisheries, other aquatic products, flood pulse agriculture) against benefits provided by regulated rivers (hydropower, irrigation, flood control).

Over the past 20 years, research has greatly improved understanding of the functioning and importance of rivers systems in the region, and the hydrological consequences and economic benefits of river regulation are now relatively well understood. Unfortunately, the ecological consequences and economic costs are not nearly as well defined. As a result, the debates on water resource development are skewed by both overly optimistic projections of development outcomes, and by alarmist predictions of ecological catastrophe. Economic and demographic change in the region is progressing at a rapid pace and water resource development will not wait on a full exploration of the research issues. Decisions must be made using the best available information, and with recognition of the risks involved. There is a critical need for an improved policy analysis to inform decision makers about the enormous trade-offs that are at play, particularly in view of the current emphasis on large-scale water infrastructure for both hydropower and irrigation.

Meeting the region's food requirements over the coming decades will require significant increases in productivity in both irrigated and rainfed production systems. It is increasingly clear that rice production alone can deliver neither food security nor poverty reduction, and diversified agricultural systems are essential to increase productivity and reduce agricultural risk. Rainfed agriculture is likely to continue as the dominant production mode in the GMS for the foreseeable future, and agricultural water management approaches are needed to reduce water-related risks and support diversified production. The focus for investment in agricultural water management must shift from large-scale irrigation systems designed for rice to more flexible approaches, including small-scale, on-farm systems and groundwater irrigation, particularly in the large alluvial floodplains where aquifers are recharged by annual floods. A comprehensive assessment of groundwater resources (including surface and groundwater connectivity) is needed as the basis for coordinated water resources planning.

Proposed hydropower development in the major river basins of the GMS will result in changes to river flows at a previously unprecedented scale and rate. The importance of freshwater fisheries to food security in the region underscores the importance of protecting the productive capacity of freshwater ecosystems from the impacts of these changes. This requires attention not only to environmental flows, but also to habitat coherence and connectivity at the landscape scale. Given the importance of migratory fisheries to regional food security, a precautionary approach to development is warranted until a clearer picture emerges of the risks involved. Research to date indicates that the adverse consequences of dams on tributaries are both more localized and better understood than those of developments on the mainstream: the advice of ICEM (2010) for a moratorium on Mekong mainstream development, compensated by fast-tracking tributary dams, appears to offer a lower-risk development path.

A high proportion of the research effort in the region has focused on the Mekong: hydrological and ecological information for the region's other major river basins is limited, and this lack will severely constrain planning and monitoring of water resources. Compilation of consistent hydrological data and models across the GMS and assessments of flow requirements to protect ecological functioning of all major rivers in the basin should be an urgent priority.

Much of the investment in agriculture, mining, and hydropower that will define water resource use in the

GMS over the next 10 years will be driven by the private sector. Even when standards for impact assessment of individual projects are met, there is rarely adequate analysis of the cumulative benefits and impacts of multiple projects at the basin, catchment, or national scale. It is the role of national governments to retain a strong focus on strategic assessments of the overall economic, social, and environmental sustainability in planning infrastructure development, but such approaches will only be successful if ways can be found to involve private sector investors and local communities (Campbell *et al*., 2011) in planning at the early stages.

Projections indicate that the impacts of climate change on water resources in the GMS over the next 20–30 years are likely to be small compared to the impact of economic, demographic, and environmental changes. This "breathing space" provides an opportunity for countries and communities to reshape their water management systems and to deal with the more extreme changes expected after 2050. The most effective strategies for adaptation will be those that promote more productive water use, reduce water-related risk and vulnerability, and build the overall resilience of rural and urban communities.

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DEVELOPMENT AND APPLICATION OF A LAND-USE PREDICTION MODEL FOR FUTURE WATER RESOURCES MANAGEMENT IN THE GREATER MEKONG SUBREGION

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Abstract

Land-use prediction is one of the biggest planning challenges in the Greater Mekong Subregion (GMS) because of the rapid and dynamic changes in its economy, society, and environment. At various sites in the GMS, there are major processes affecting land-use change, including (i) deforestation of the native rain forest, (ii) expansion of agricultural areas, and (iii) development of plantation forests, such as rubber-tree planting for commercial purposes. We developed a land-use prediction model to reflect these major processes, using as the study area the 3S sub-basins (Sekong, Sesan, and Srepok)—a part of the Lower Mekong River Basin, including land in Cambodia, the Lao People's Democratic Republic, and Viet Nam. We then used this model to predict land-use change and water demand increase over the next 20 years due to agricultural area growth.

Two scenarios were considered for agricultural area growth: Scenario 1 for aggressive agricultural growth and Scenario 2 for moderate agricultural growth. The major difference between the two scenarios is whether we consider abandonment of agricultural area a major land-use change process (Scenario 2) or not (Scenario 1). Both scenarios show that agricultural area would grow in Srepok sub-basin. However, in Sekong and Sesan, Scenario 2 shows that agricultural area may shrink over time, while Scenario 1 shows positive agricultural area growth. From the available information, it is hard to decide which prediction is the more likely one. However the model was developed as a tool so that the user can modify model parameters at any time. Future agricultural water demand projections showed that water demand in Viet Nam would keep increasing and the demand would become intensive, especially upstream of the Srepok River basin.

1. Introduction

As a direct driver of environmental change, changes in local land use affect not only the welfare of human beings but also ecosystem services (Millennium Ecosystem Assessment, 2005). In the field of hydrology, the impact of land-use change on water resources is considered as potentially large, but quantifying these impacts remains one of the more challenging issues (Stonestrom *et al.*, 2009). Land use is an important factor in hydrology, because its changes can affect key atmospheric elements of the hydrologic cycle, including evapotranspiration, precipitation, and land-surface temperatures (Feddema *et al.*, 2005; Turner *et al.*, 2007). And large-scale land-use change can modify regional weather patterns and future climate (Foley *et al.*, 2005; Schilling *et al.*, 2008; Zheng *et al.*, 2009). Also, land-use changes can have impacts on water quality by altering sediment budgets; salinizing soil water, groundwater, and surface water; and introducing chemical compounds, such as nitrogen and phosphorus (Schlesinger *et al.*, 2006). Land-use impacts are not limited to irrigated areas by releasing fertilizer; urbanizations also affect water resources locally, impacting water quality, storm discharge, and groundwater recharge.

Substantial scientific investigations are being conducted to understand the impact of land-use change on water resources, and this relationship is being explained in steadily more advanced ways. On a parallel with these scientific inquiries, a method is needed to assess the impact of land-use change on water resources to support decision makers in city and regional planning dealing with climate change and water resources adaptation and policy. Advanced analytical techniques and precise data are required for making such plans and policy, but this is often difficult for underdeveloped countries due to shortages of technology, funding, and human resources. In order to address this issue, a reliable and easy-to-handle method for modeling land use for water resources assessment must be developed that can be applied by decision makers and planners using available data in developing regions, such as the Greater Mekong Subregion (GMS). This paper describes the development of such a tool and its application in the 3S sub-basins, and discusses the implications for future water demand and availability.

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2. The 3S Sub-Basins

2.1. Outline

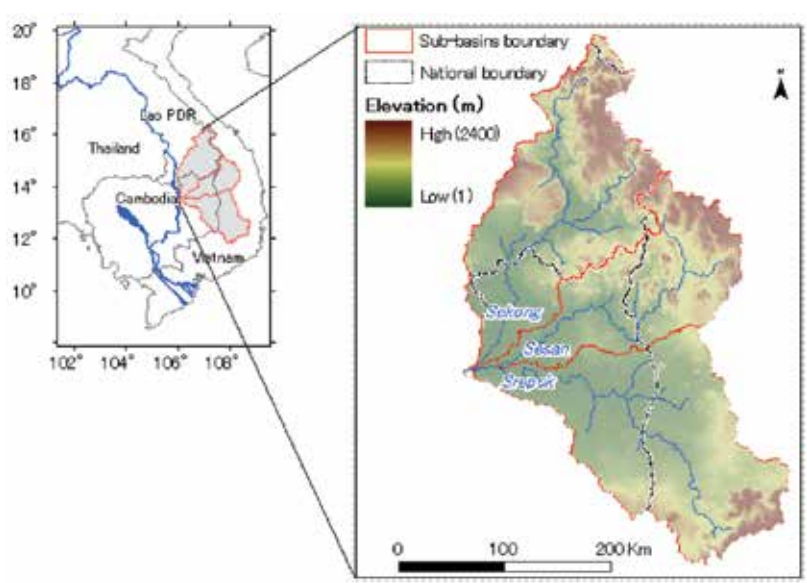
The study area was the 3S sub-basins, named for the three sub-basins it contains (Sekong, Sesan, and Srepok), in the Lower Mekong River Basin on the Indochinese Peninsula, including land in Cambodia, Lao People's Democratic Republic (Lao PDR), and Viet Nam (Figure 1). The 3S area of 78,650 km^2 is the largest tributary system of the Mekong River Basin (Mekong River Commission, 2007), which is divided between the three countries, with 33% of the area in Cambodia, 29% in the Lao PDR, and 38% in Viet Nam. It covers about 10% of the area of the entire Mekong Basin and contributes 17% of the total run-off (World Bank, 2006). The Mekong River Commission (MRC) Basin Development Planning project (2009) identified the area as a region where considerable development potential exists and as a result, multilateral development banks have been investigating it. The World Bank (2006) studied the water resources assistance strategy for integrated development and management from the 1990s. The Asian Development Bank (ADB, 2009) has been supporting arrangements to strengthen regional cross-border collaboration at the request of the national Mekong committees of the governments of Cambodia, Lao PDR, and Viet Nam since April 2006.

In relation to its large area, the total population is low, about 2,900,000 in 2004, but the population growth rate is much higher than the national average in each country. The social and economic development and resulting environmental pressures are higher in the upstream than the downstream regions. Precipitation varies across the 3S, ranging from about 1,500 mm in the downstream areas and middle reaches of the Srepok to greater than 3,000 mm in the upstream portions of the Sekong and Sesan sub-basins.

2.2. Land-Use Change in the GMS

The deforestation and clearing of land for permanent cultivation and increased cultivation of annual crops have already led to a measurable increase in the frequency of flash floods in the upper catchments and there are indications of declining low flows during the dry season (Qiu, 2009; Ziegler *et al.*, 2009). The Mekong Water Resources Assistance Strategy report (World Bank, 2006) described the impact of land-use change to water resources as follows: "The stability of the hydrological systems and local climate, however, is threatened by degradation of critical watersheds, most significantly by deforestation in the upper catchments, but also by increasing cultivation of annual crops and abstraction of groundwater for irrigation on the plateaus." Change in land use is one of the critical factors impacting water resources in the Mekong watershed, including the 3S watershed, and potential change in land use in the future is critical for water resources planning and management. The growing number of hydropower dams should be also addressed. As of February 2009, 9 hydropower plants were in operation, 8 were under construction, and 24 were still in design or planning

Figure 1: Research site



stages (ADB, 2009). With development proceeding in the region's countries, power demands are expected to rise 7% per year over the next 20 years (MRC, 2010), yielding a substantial—and potentially lucrative—energy market.

2.3. Data Availability

In the 3S sub-basins, the most prominent land-use change processes are deforestation, agricultural expansion, and regrowth using commercial trees (Qiu, 2009; Zieglear *et al.*, 2009). The developed land-use model included these processes. The model was developed based on available literature, field visits, and land-use change trends captured from available data sets. It was challenging to prepare land-use data for various periods across 3 countries. We used land-use data at three points of time (1993, 1997, and 2002–2005). For 1993 and 1997, the integrated land-use data edited by the MRC were available with consistent land-use categories in the entire region. For the latest land-use data, however, only official individual national land-use data were available (Save Cambodia's Wildlife, 2006; Messerli *et al.*, 2008; FAO, 2009). Therefore, we combined these data into an integrated land-use data set for the entire basin.

Combining the three 2002–2005 land-use data from different sources was difficult as the categorization was largely different. In this study, MRC 1993 and 1997 data were primarily used and the latest 2002–2005 combined land-use data were supplementary and used to understand more recent trends in land-use change in the region. Figure 2 shows the MRC 1993, MRC 1997, and combined 2002–2005 land-use data.

To understand the trends of land-use change in the 3S sub-basins, first the MRC 1993 and 1997 land-use data were simplified into 5 major categories: forest, agriculture, mosaic, regrowth, and inactive. Inactive refers to the areas where land-use change may not be significant, such as water and wetlands. Urban area was also included in the inactive category because urban expansion was not considered in this study. Table 1 shows the original and simplified major land-use categories in the MRC data. A variety of studies in the forestry sector indicate that trends in forest changes accelerated during 1997–2002 and further increased between 2002 and 2005 (Save Cambodia's Wildlife, 2006). Regarding population density in 1995 and 2005, the Gridded Population of the World data with grid resolution of 2.5 arc-minute were used (CIESIN, 2008).

Figure 2: 3S Sub-Basins Land Use in 1993, 1997, and 2002–2005

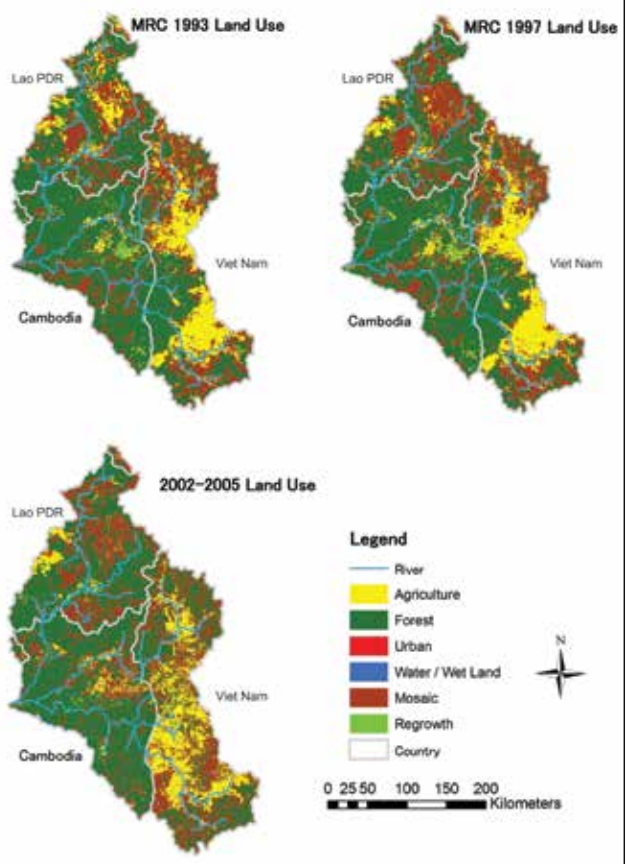


Table 1: Re-categorized Mekong River Commission Land-Use Classes

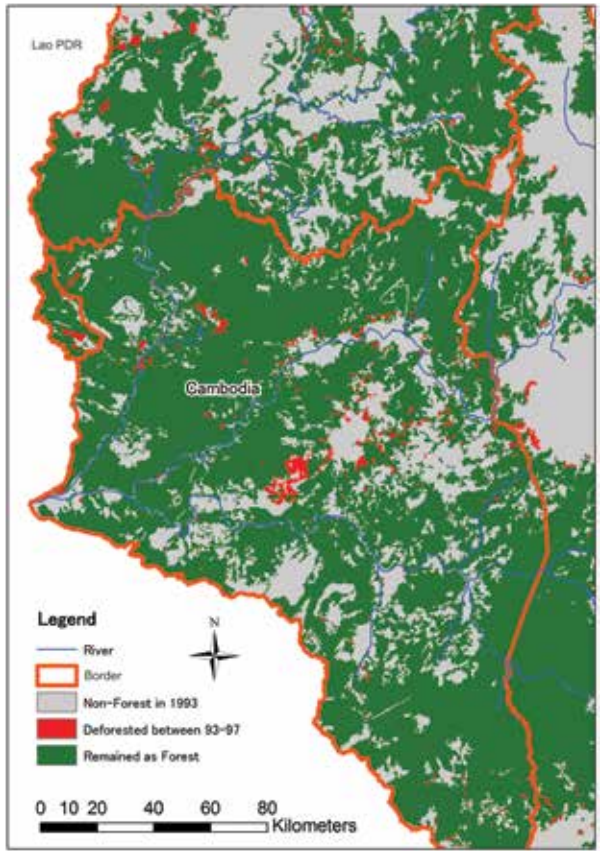
Simplified Major Category	MRC Original Category
Forest	Evergreen, high cover density; evergreen, medium-low cover density; mixed (evergreen and deciduous), high cover density; mixed (evergreen and deciduous) medium-low cover density; and deciduous
Agriculture	Plantations; Cropping mosaic, cropping area < 30%; cropping mosaic, cropping area > 30%; and agricultural land
Mosaic	Evergreen mosaic; mixed mosaic; deciduous mosaic; wood- and shrub land, evergreen; grassland; bamboo; wood- and shrub land; and barren land
Regrowth	Regrowth
Inactive	Urban or built-over area; water; other; wetland; and clouds

3. Analyzing Land-Use Change Trend

Table 2 shows area change for each land use from 1993 to 1997. Forest area was reduced by 974 km^2 or 2.2% in 4 years. Agricultural area was increased by 42 km^2 or 0.3%, while mosaic area increased by 1,339 km^2 or 8%. The total agricultural area did not change much; however, there was active expansion and shrinkage of agricultural area during the period: 17% of the 1993 agricultural area became mosaic by 1997 and 17% of the 1997 agricultural area was not agricultural area in 1993. The active change in agricultural area may include the slash-and-burn short-term agriculture, including rubber tree plantations in mountainous areas on the east side of the 3S basin. In these areas, forest area becomes agricultural land for several years, then becomes barren, grass land or different types of agriculture after the land is abandoned.

Figure 3 shows deforestation areas during 1993–1997. Among the deforested areas about 60% became agricultural and 40% became mosaic. As Figure 3 shows, deforestation tends to occur from the outer edge of the forest area because of accessibility from villages and roads. After deforestation, the land would have a new land use depending on the ambient land use. The 2002 land-use data show this trend well. A large agricultural area, next to forest area in the south of Viet Nam in 1997, significantly expanded in the northeast toward the border with Cambodia in 2002–2005.

Figure 3: Deforested Area in 3S Sub-Basins between 1993 and 1997



4. Land-Use Prediction Model

4.1. Model Development

One of the most frequently used approaches in land-use prediction is logistic regression (Ty, 2011). However, instead of relying on statistics, we chose to develop a model that can reflect the trend qualitatively observed from the historical land-use data. Also, to use the model as a planning tool as well as a land-use prediction tool, we made the model flexible and kept model parameters as variables so that the user can give target values for future land-use prediction.

Based on the observed trend in land-use change and available literature statistics, assumptions for land-use prediction were set as follows:

1) Deforestation rate per every 5 years was fixed as C_{DF} = 3% until 2032.
2) Regrowth rate in Viet Nam was about 1/3 while those in Cambodia and the Lao PDR weree only 6% (Tanji,

Table 2: Land-Use Change from 1993 to 1997

	MRC 93 (km^2)	MRC 97 (km^2)	Change (km^2)	Change (%)
Forest	43,855	42,881	-974	-2.2
Agriculture	12,269	12,311	42	0.3
Mosaic	17,064	18,403	1,339	7.8
Regrowth	1,339	1,164	-175	-13.1
Inactive	3,910	3,677	-232	-5.9
Total	**78,436**	**78,436**	**-**	**-**

2005). For simplicity, a uniform forest regrowth rate of 25% was used within the 3S sub-basins (C_{RG} = 0.25).

3) Among the deforested area, 75% was assumed to become agricultural area.

4) The deforestation process was considered as nonreversible, starting from forest, going through agriculture, mosaic, then ending as regrowth. Table 3 shows the possible next land use after every 5 years. As shown in the table, direct changes from forest to regrowth and agriculture to regrowth were ignored.

5) Density was primarily used to prioritize the cells subject to change. This is based on the trend that deforestation and agricultural area growth tends to occur from the edges of the existing and next land use. For example to predict cells where forest becomes agriculture, density of agricultural area was calculated for each forest cell within a radius of 30 cells and these were ranked based on the density. The highly ranked cells within the pre-fixed number of changing cells were transformed into agriculture.

With these assumptions, two scenarios were developed; the direction of land-use change is illustrated in Table 3:

Scenario 1: Aggressive agricultural growth. This scenario assumes no agricultural area will become mosaic land-use type. This assumption implies that no agricultural area is abandoned (i.e., C_{AB} = 0).

Scenario 2: Moderate agricultural growth. This scenario suppresses the rate of agricultural area growth. While new agricultural area is created from 75% of deforested area, existing agricultural area decreases at the rate of 2/3 of the new agricultural area generated. (i.e., $C_{AB} = 0.5C_{DF}$).

With the current area ratio of forest (X_F^O), agriculture (X_A^O), mosaic (X_B^O), regrowth (X_R^O), and inactive (X_I^O)as initial conditions, the future area ratio (X^1) for each land use can be predicted with the assumptions described above.

$X_F^O + X_A^O + X_B^O + X_R^O = X_F^1 + X_A^1 + X_B^1 + X_R^1 = 1 - X_{IA}^1$ (Total balance)

$X_F^1 = (1 - C_{DF})\, X_F^O$ (Forest)

$X_R^1 = X_R^O + C_{BR}\, X_B^O$ *where* $C_{BR} = C_{RC}\, C_{DF}\, X_F^O$ (Regrowth)

$X_A^1 = (1 - C_{AB})\, X_A^O + C_{FA}\, C_{DF}\, X_F^O$ (Agriculture)

The process was integrated into a model using the ArcGIS Model Builder function. Figure 4 shows the entire model procedure for Scenario 2. The model represents the complete process needed to predict the next 5 years of land-use change. The model first calculates the probability of change based on the density of potential next land use; then ranks changes based on their probability, and allocates the next land use based on the rank and pre-fixed total number of cells subject to change. Putting all single processes together as a single tool helps the user reduce errors because the user does not need to deal with intermediate files and it is easy to test different scenarios.

Figure 4: Model Process to Predict the Next 5-Year Land-Use

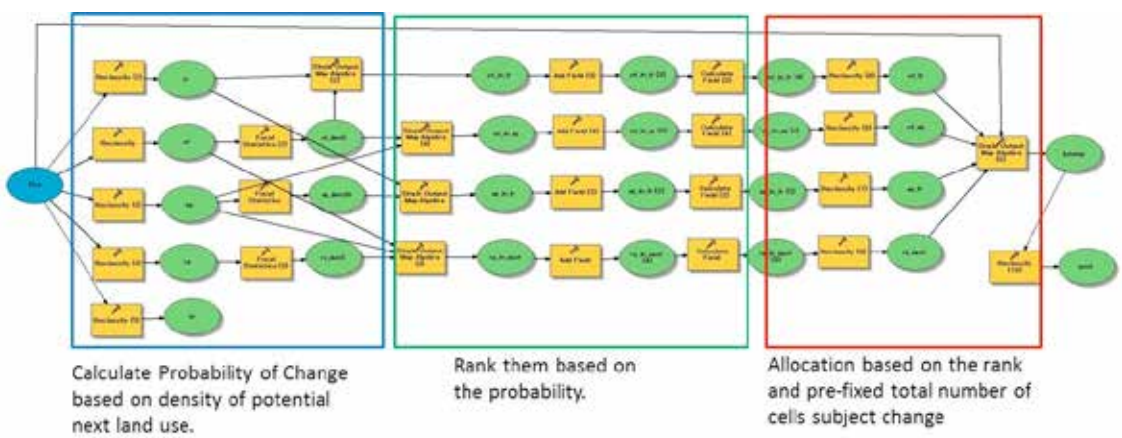


Table 3: Assumed Rule for Land-Use Change

		Future Land Use[a]			
		Forest	Agriculture	Mosaic	Regrowth
Existing land use	Forest	XX	XX	X	
	Agriculture		XX	X	
	Mosaic			XX	X
	Regrowth				XX

Note: a Values are XX for both scenario 1 and 2, X for scenario 2 only.

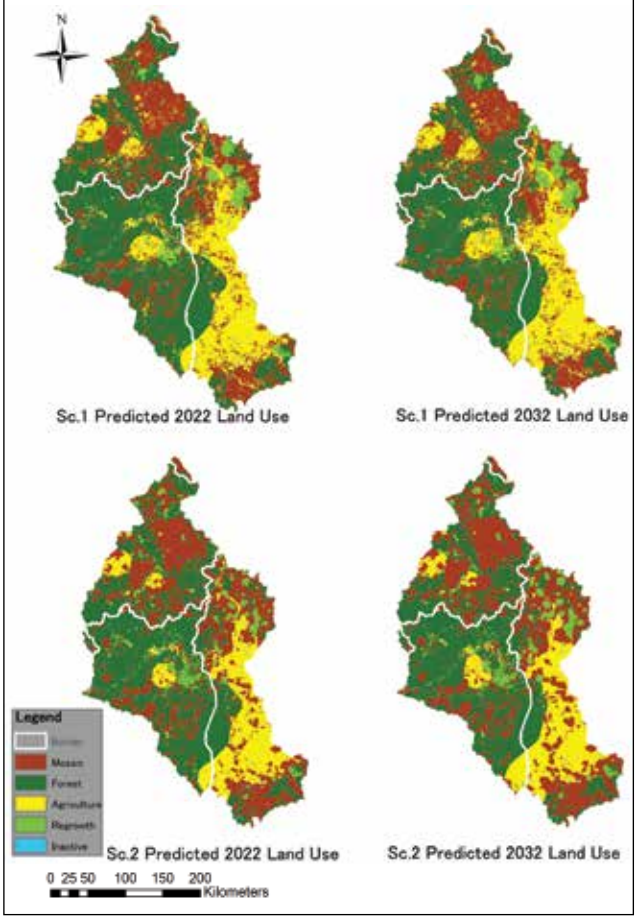
4.2. Predicted Future Land Use

Figure 5 shows predicted 2022 and 2032 land-use maps for the two scenarios. In Viet Nam forest area would become very small due to intensive expansion of agricultural and mosaic areas. In Cambodia and the Lao PDR, forest area would be diminishing due to expansion of sporadic growth of agriculture and mosaic areas. Figure 6 shows the predicted agricultural area change for both scenarios. Both scenarios predict that the Srepok basin will experience strong growth of agricultural area whereas it was not clear whether Sesan and Sekong will have growth in agricultural area. The land-use change trend and prediction are worth checking after the next MRC land-use data are published.

There are several limitations of model: (i) Urban area: In this research, urban area expansion was not considered. (ii) Thick vs. thin forest was not considered; however, the MRC's 1997 vegetation cover inventory reported that thickness of forest is different depending on the level of deforestation while runoff pattern can be different as well. (iii) Preserved area: There are some protected areas in the 3S sub-basins. However, such data were not available throughout the sub-basin expanse. Thus, this aspect was not considered in the prediction.

It should be noted that the land-use prediction model was also developed as a tool. Users can change or modify parameters globally and locally to improve prediction. The model can be used as a planning tool by setting a goal, such as lower deforestation rate than existing, and visualizing the difference in prediction maps.

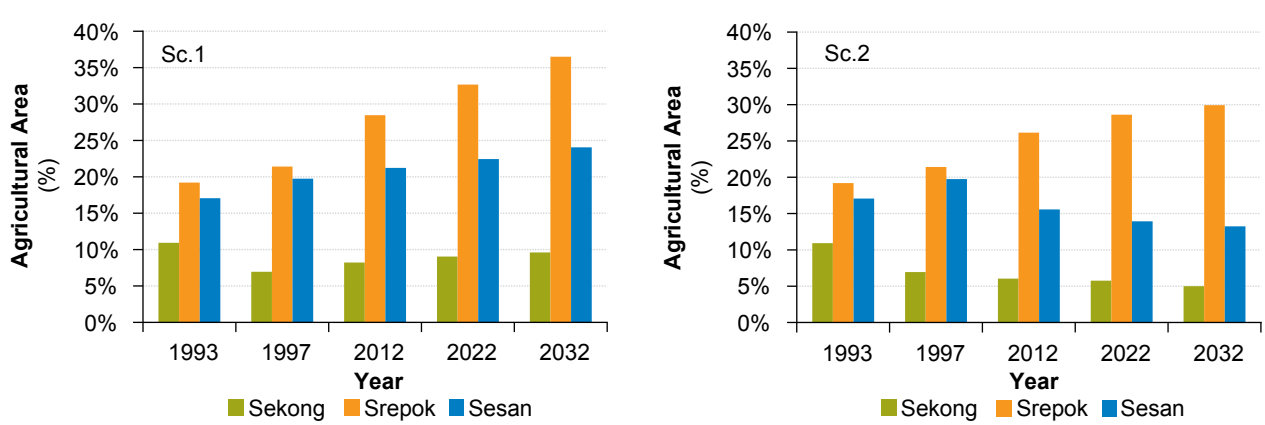
Figure 5: Predicted 2022 and 2032 Land Use for Both Scenarios



4.3. Impact of Agricultural Area Growth on Water Demand

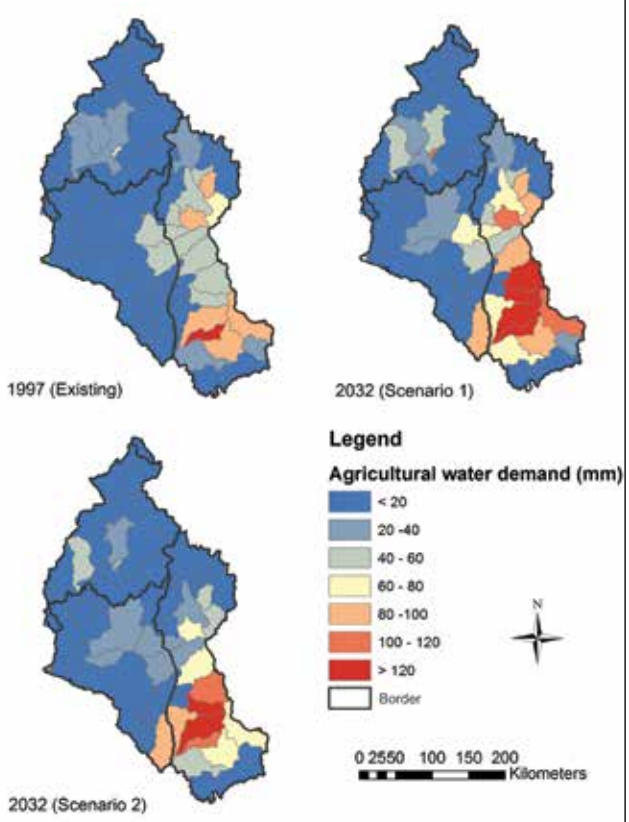
The predicted land-use map was used to evaluate the impact of land-use change on water demand at the sub-watershed scale. For each sub-delineated sub-watershed, existing and future water demands were calculated.

Figure 6: Predicted Agricultural Area Change for Each Sub-Basin for Both Scenarios



Agricultural water demand calculation was done separately for wet and dry seasons. During wet months (April–September), a value of 0.27 million cubic meters per square kilometer per year (MCM/km^2/yr) was used (Kawasaki, *et al.*, 2010) and for dry months (October–March), 0.54 MCM/km^2/yr. During dry months more water is needed for agriculture, but only for areas where irrigation is available. In the 3S sub-basins, total available dry irrigation is about 0.8% in Cambodia, 2.2% in the Lao PDR, and 7.8% in Viet Nam, (3Ss Basins, 2011). The ratio was uniformly applied in each country to calculate dry-season agricultural water demand. Figure 7 shows existing and predicted 2032 agricultural annual water demand for the two scenarios. The prediction shows water demand in Viet Nam would keep increasing and the demand would become intensive, especially upstream of the Srepok River basin.

Figure 7: Calculated Agricultural Water Demand in 2032 for Both Scenarios



5. Conclusion

In this study, a land-use prediction model was developed for predicting future agricultural water demand. Two scenarios were considered for agricultural area growth: Scenario 1 for aggressive agricultural growth and Scenario 2 for moderate agricultural growth. The major difference between the two scenarios is whether we consider abandonment of agricultural area a major land-use change process (Scenario 2) or not (Scenario 1). Both scenarios show that agricultural area would grow in Srepok sub-basin. However, in Sekong and Sesan, Scenario 2 shows that agricultural area may shrink over time, while Scenario 1 shows positive agricultural area growth. From the available information, it is hard to decide which prediction is the more likely one. However the model was developed as a tool so that the user can modify model parameters at any time.

Based on the two 2032 land-use predictions, future agricultural water demand was calculated for each sub-catchment. The prediction shows water demand in Viet Nam would keep increasing and the demand would become intensive, especially upstream of the Srepok River basin.

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CHALLENGES FACING COOPERATION AND SUSTAINABILITY ON WATER SECURITY AND HYDROPOWER DEVELOPMENT IN THE MEKONG RIVER BASIN: THE GMS RESPONSE

Suzanne Ogden[1]

Abstract

The GMS faces many challenges as it tries to establish a framework for poverty alleviation and sustainable development in the GMS. This paper examines why the "science" of development has been secondary to the politics of development in the GMS, and especially within the Mekong River Basin (MRB) itself. It highlights the relationship of Yunnan Province to the Central Government of the People's Republic of China (PRC), and contrasts the role of Yunnan Province as China's "Gateway to the South" with the role of Guangxi Zhuang Autonomous Region in the GMS. The paper points out the conflicting viewpoints and objectives, not only among the MRB/GMS states, but also among the ministries within these states, within the Mekong River Commission (MRC), within the donor community, and among all these and the investors in the MRB/GMS. As the uppermost riparian country on the Mekong River (known as the Lancang River in the PRC[2] the PRC has had few incentives to share in the costs that hydropower and natural resource development can impose on downstream riparian countries; but the PRC's approach to natural resource and hydropower development has not necessarily differed from that of the lower MRB countries. Nor has the impact of the PRC's development necessarily been detrimental to the Lower MRB countries. However, with the creation of the GMS, which is conceptually, geographically, and economically broader than just the MRB, the PRC has far more reasons to share in the costs and benefits of development for all states in the subregion. This may, in turn, result in agreements concerning the sustainable development and security (national, food, energy, water) of the MRB/GMS countries.

Introduction

In a zero-sum situation, countries try to get absolute gains, forcing others to accept absolute losses. Upstream riparian countries often seem to take this approach to their control of water as it flows through their sovereign territory. If we construct a scenario in which one or more countries are "losers," their food and water security is endangered, and their natural resources are exploited in an unsustainable way, ultimately all lose. Indeed, it can be quite costly for the "winners," who often must respond to disruptive and costly protests in response to their development projects. This has been an issue for the stakeholders in the Mekong River Basin (MRB).

If a non zero-sum strategy is pursued, actors share in costs as part of the package of expanding the benefits. A non-zero sum approach is essential for cooperation on national, food, water, and energy security as well as for sustainable development, because all countries will feel that they will gain—even if they have to bear some costs. The Greater Mekong Subregion (GMS), by facilitating a framework for increasing the benefits to all member states, has somewhat improved cooperation and benefit sharing on the difficult issues of water, energy, and natural resource sustainability and development in the MRB and GMS. Thus far, most of the investment in the GMS has been in transportation and energy infrastructure. This is vital for developing tourism and the extraction of natural resources—and to poverty alleviation.

This paper looks at the challenges facing the GMS as it tries to establish a framework for poverty alleviation and sustainable development. However, it should be noted that there are some problems facing the region that are beyond the control of the GMS and sometimes beyond the power of its member states acting individually. For example, fluctuations in the global price of crops, such as rice, fish, coffee, rubber, or oil, may have much more impact on the poverty of farmers and fishers than does the construction of a dam. These global prices may be dramatically affected by weather (including climate change) or wars, or by subsidies given to major producers or exporters of these products elsewhere, such as in Europe and the United States. On the other side, a GMS government's own policies that tax or subsidize farmers and fishers, or which carry out rural electrification, may make or break their livelihoods.

The second major factor that makes poverty alleviation and sustainable development such a challenge for the

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[2] Mekong (湄 公 河) or Lancang River (Lancang Jiang, 澜沧江)

GMS is the rapid and uncontrolled population growth in the subregion. The population of the five GMS countries and the two provinces of the People's Republic of China (PRC) (Yunnan and Guangxi) in the GMS is projected to increase by about 17%, from 318.43 million in 2010 to 371 million by 2030. (Most of the growth is in Cambodia, where population is projected to grow 22% by 2030, with 25% growth in the Lao People's Democratic Republic (Lao PDR). Myanmar's population is projected to grow at 15%, while Thailand's will only grow 5%. The demand for energy, water, natural resources, and food will, given continued population growth rates, greatly outstrip their current supply by 2030 (Rogers, 2012).[3] As long as governments lack the political will to address population issues, GMS efforts to bring about poverty alleviation and sustainable development will be thwarted. Within this difficult context, there are still further challenges for the GMS.

This paper is based on research on the MRB and GMS, including findings from a field trip to Yunnan Province of the PRC, Cambodia, the Lao People's Democratic Republic, and Thailand. During this trip, a team (Professors Peter Rogers, Akiyuki Kawasaki, and the author) met with government and institution officials, academics, nongovernment organizations, farmers, and fishers. Annex 1 gives a list of the persons and institutions visited.

1. Toward Sustainable Development in the GMS

The "science" of development—for example, the impact of irrigation and dams on hydrology, the environment, fishing, forestry, and people's livelihoods—has really been secondary to the politics of development in the GMS (Molle *et al.*, 2009). This is to some degree because there are enough "facts" available for everyone to choose the facts most appropriate to their own position. The interests of virtually every sector, group, institution, ministry, and country in the GMS can easily rely on facts that reflect their preferences. Perhaps the overriding problem is that the largest stakeholders (such as construction companies, fisheries, developers, governments, politicians, and investors) have a huge amount at stake in the development of the MRB and GMS.

There are conflicting viewpoints and objectives, not only among the MRB/GMS states, but also among the ministries within these states, within the Mekong River Commission (MRC), within the donor community, and among all these and the investors in the MRB/GMS. Indeed, there is disagreement even among the various states' own ministries that are concerned with matters related to the MRB/GMS environment, natural resources, water, and economic development.

There are, of course, many stakeholders in the GMS who suffer from the decisions made by state actors, construction companies, investors, and others. The support or opposition from those affected by development, such as farmers and fishers in certain areas, vary widely depending on the type of development project, the state in which it occurs, and where they live. Even the poorest fishing communities do not necessarily agree on whether they want their livelihoods protected, or whether they would prefer, given the option, to leave behind their traditional livelihoods if they were adequately compensated or could find alternative livelihoods—especially for their children.[4]

An additional problem for sustainable development in the GMS is that national governments do not make decisions based on environmental impact assessments. This is because ministries of the environment tend to be weak vis-à-vis ministries that are involved with energy, water, and construction. The more they build, the better, because these ministries get more power (and dollars for themselves) from such things as building dams. Ministries get nothing from protecting fish, communities, livelihoods, or the environment. Speaking for the poor gives no power to a ministry.

There is no disinterested national actor in the GMS who puts the interests of the region as a whole ahead of its own national interests. Thus, there is little agreement on many issues that concern water, natural resource exploitation, and development among the national actors in the GMS. As a result, each GMS state tries to act in its own national interests. Because national interests take precedence, GMS states tend to resist regulation from international or regional bodies. Further, because there are many international agencies and donor states involved, it gives the individual states of the GMS a chance to maneuver among them and to choose their best options from among those offered.

[3] This would be a 1.7% annualized growth rate for the GMS.

[4] National and international nongovernment organizations often try to protect the livelihoods of fishers and farmer-fishers, regardless—or even especially—if they are at subsistence level, whether they want it or not. A frequent criticism is that they appear to speak on behalf of protecting the fish, wild life, and the trees, rather than for the people.

Almost all the GMS actors belong to more than one development cooperation network (such as the GMS, the MRB and the Greater Bei Bu Gulf Regional Economic Cooperation Organization), so each of the states is paying attention to its interests in more than just the GMS.(Binh, 2006, p. 81) Thus, within the MRB, as within the GMS, states tend to make bilateral or multilateral deals with each other, rather than cooperating with the MRC and adhering to its recommendations concerning water, natural resources, and the environment. Nevertheless, within the GMS framework, these countries are making important investments in infrastructure, notably in roads, railroads, port facilities, tourism, and trade.

Further, there is little agreement among the various stakeholders within a state. Stakeholders include construction companies, ministries, the public, nongovernment organizations (NGOs) (some of which are called international NGOs because of international sponsorship), banks, and affected communities. Those stakeholders who benefit the most from dams, such as urban communities that get more electricity and better control of flooding, are not necessarily the stakeholders who have to pay the costs of (or suffer from) development.

2. Role of the PRC

2.1 Water Resources Management

In 2002, the World Bank concluded that the PRC generally had been quite successful, even too successful in some cases, "in constructing infrastructure to develop and control water resources;" but it had been less successful in "establishing the institutional framework and systems needed for efficient management of water resources" (World Bank, 2003).

Seven years later, in 2009, the World Bank issued another report that pointed out virtually the same problems of fragmentation in the PRC's water resource management system: "Horizontally, at every level of government, several institutions are involved in water management, with frequent overlaps and conflicts of responsibilities….The water management system is also vertically fragmented. It is mainly built upon the administrative boundaries of different levels of government rather than at the river basin level. Each level of government has its own focal points and priorities. This makes the management of trans boundary rivers—most of the PRC's rivers—very difficult" (World Bank, 2009).

Perhaps worse as far as the MRB/GMS is concerned, although the PRC has established river basin management commissions (RBMCs) for seven of its large rivers (under the Ministry of Water Resources), they "have limited power and *have no representatives from the affected local governments in the basin*" (World Bank, 2009). Further, the Lancang/Mekong River is managed by the Yangtse River commission, not by its own RMBC.[5] Possible solutions that would lead to more integrated water resource management have not been tried.

One of the primary emphases of the PRC's 12th Five-Year Plan (2011–2015) is sustainable growth in the development of clean energy, energy conservation (which entails reducing the intensity of energy use per unit of production), and diminishing the negative effects of energy development on the environment. Hydropower is one of the sustainable sources to be tapped, with its role potentially expanding because of the Japanese earthquake and tsunami in March 2011 that led to a crisis for its nuclear power plants. This has resulted in a rethinking of the vast planned expansion of nuclear power announced in the 12th 5-year plan and perhaps more emphasis on hydropower. It remains to be seen whether the PRC can take into account sustainability, as well as the costs and benefits to its own citizens in Yunnan Province and those of the citizens of the MRB as it develops dams on the Lancang/Mekong, extracts natural resources, and builds infrastructure.

2.2 Role of Yunnan Province

In Yunnan Province, there is considerable discord among stakeholders as well as academics and local and international NGOs over the issue of whether hydropower should be developed in order to address the grinding poverty of many of the people living in the Nu and Upper Mekong River Basins (about 10 million people), or whether the priority should be protecting the environment—especially the "Grand Canyon" of the PRC formed by the three rivers—the Nu, the Mekong/Lancang, and the Yangtse (Sun and Zhao, 2008).

The debate is framed to reflect the interests of each side. To the Chinese "anti-dam" (and perhaps anti-development) groups, "protecting the environment" means keeping it in its pristine state (which they insist still exists). They argue

[5] Within Yunnan, the river is managed by the Suili Bu (Water Power Agency).

that the damage done by dams to fisheries, wildlife, and forests is unacceptable. For the Chinese pro-dam groups, the only issue of "environmental protection" is stopping pollution of the environment. There is, in their view, no pristine environment to protect. They argue that building dams for hydropower, regardless of the damage it does to fisheries, wildlife, or forests, aids poverty alleviation without polluting the air or adding to the greenhouse gases that are contributing to climate change. (Mertha, 2008: 110-149) The alternative, building coal-fired plants, may help development, but at enormous costs to the environment. Apart from emitting greenhouse gases, the production (mining and processing) and consumption of coal power, is the largest industrial use of water in the PRC. (Liu, 2011; Circle of Blue, 2011) Thus, building more coal-fired plants for electricity affects both the quality of the air and water, and itself puts strains on the supply of water.

So for Yunnan, there will be significant costs to one stakeholder group or another, regardless of what choice is made—even if the choice is to protect the environment by keeping it "pristine." This same dilemma confronts other GMS states as well—a dilemma exacerbated by yet other concerns over building nuclear power.

The PRC's central Government considers that Yunnan's policies are not in line with the da qu (big community) national viewpoint. That is, Yunnan has done things in its relationships with GMS/ASEAN countries that cross the line between "foreign policy" (which the central Government's Ministry of Foreign Affairs reserves for itself) and "external relations" (which Yunnan as a province is permitted to do). Yunnan may be undertaking "foreign policy" that serves its narrow local interests, rather than approved "external relations" that serve the needs of the "big community." (In Yunnan, as in other provinces, there is a waiban in charge of "external relations"—but any decisions it makes must be approved by the Ministry of Foreign Affairs.)

One example is Yunnan working with a Malaysian multinational rubber company, which has a branch office in Yunnan. In recent years, this company has been replacing Yunnan's local vegetation with rubber plantations. When the drought hit Yunnan in 2010, its farmers did not even have enough water to drink, much less grow crops. The central Government considers that the rubber trees, which need a lot of water, contributed to the drought. Also, since rubber trees do not have deep roots and do not hold water well, they do not hold down the soil and can contribute to erosion. As a result, the local people suffered, while the rubber plantation operators profited.[6] Further, the central Government's view is that rubber plantations are undercutting Yunnan's biodiversity and wants to limit the policies Yunnan pursues with MRB/GMS and Association of Southeast Asian (ASEAN) countries and companies.

Judging from this type of conflict between Beijing and Yunnan, it appears that sometimes the PRC's central Government is more concerned than Yunnan's provincial government about the impacts of provincial policies on poverty, the environment, and biodiversity. (Note, however, that Chinese companies are likewise buying concessions and contracting farmers to grow rubber in the Lao PDR [Asia Times online, 2011]) In other situations, however, it may well be that the provincial government wants to cooperate with the GMS and the MRC in a way that improves the governance of the region—but is not permitted to do so by the PRC's central Government. For example, because the latter considers information about any transnational river, such as the Mekong, a "state secret," and, since transnational rivers are considered issues of "foreign policy" in the PRC, Yunnan is essentially powerless to give information to the MRC about the Lancang/Mekong River's flow, sedimentation rates, plans for building dams, and anything else that would affect the ecology of the lower MRB—unless the central Government is convinced it is in the PRC's national interest to do so.

Although Yunnan has become the best "gateway" to ASEAN and GMS countries, Guangxi Zhuang Autonomous Region's trade with the GMS was actually higher than Yunnan's in 2005–2009.[7] GMS/ASEAN states benefit from the competition between these two Chinese provinces because each tries to offer greater economic and commercial benefits to them in order to get their business (Lu and Chong, 2010, pp. 11–12).

Because Yunnan is just a poor province, it has limited economic power. Other GMS members can make decisions as national governments; Yunnan has to follow the central Government to get the relationship it wants with the GMS.

He Shengda, a leading academic in Yunnan, suggests that the "central Government should act as the decision maker

[6] According to one Chinese scholar, those who have looked at the history of Yunnan cannot find a drought with such serious consequences anywhere in the historical documents. The scholar concluded that the rubber plantations exacerbated the normal damage from drought. (Interview, 25 March 2011).

[7] This is partly because 80% of Guangxi's trade with ASEAN/GMS countries was with Viet Nam (Wong and Chong 2010), a much better developed economy than most of the countries with which Yunnan trades.

with respect to the counterpart governments of the GMS while Yunnan plays its role as the implementer of projects approved by the central Government." The Yunnan provincial government "needs the central Government's leadership, institutional and financial support, and backing for research and development on potential cooperation projects." He's 2006 suggestion that the PRC should make Kunming "the liaison center between [the PRC] and ASEAN countries;" and that the transportation networks that connect Yunnan with them should be incorporated "into the China-ASEAN Free Trade Association framework as an essential element of bilateral economic and technological cooperation…" (He, 2006, pp. 113–114) has become a reality. But perhaps his most important point is that "the PRC's interest in GMS is marginal compared to its interest in the rest of the world; whereas for Yunnan, integration, development, and trade with GMS countries is central" (He, 2006).

Since the PRC's "Develop the West" program to reduce economic and social disparities between its east coast and the western hinterland began in 2000, it has benefited Yunnan Province significantly; and the PRC's national strategy has now embraced Yunnan Province's "Gateway Project"—a reformulation of Premier Hu Jintao's statement in 2009 that Yunnan should be the "bridgehead" for the southwestern region of the PRC.[8] This strategy, originally conceived as one way to lessen conflicts along the borders with Yunnan's neighbors, has become a far more expansive economic development strategy (Lu and Chong, 2010). Further, by making Yunnan the center for the transit of goods to and from the PRC to a substantial part of the GMS, as well as to South Asia and beyond to West Asia and East Africa, Yunnan is freed from its landlocked position to become the PRC's southwestern "gateway" to the world.

Initially, however, the key components of Yunnan's "Gateway Project" are to expand regional tourism and cross-border trade while curbing illegal trade as well as human and drug trafficking; and to enhance the PRC's energy and natural resource security by making Yunnan a transportation and communication hub of the GMS area—especially to the port of Haiphong to the east, and Bangkok[9] and the Port of Mawlamyaing (formerly Moulmein, in Myanmar) to the south, giving it access to the Indian Ocean's Bay of Bengal and Andaman Sea—the southern ports being of particular importance to avoid the maritime security issues of shipping from the PRC's east coast ports to the south and west through the Straits of Malacca.[10] Expanding the transportation and commercial infrastructure is central to the PRC's effort to increase trade in the region and beyond, and to exploit the natural resources in the GMS area.[11] Almost every major infrastructure project—the railroad and road corridors, dams, and waterways that link the GMS countries and provide hydropower—has Yunnan in a key transit (and construction) role.[12] The PRC-ASEAN Free Trade Area Agreement (2002) is fundamental to Yunnan's cooperation with the GMS (He, 2006, pp. 90–92, 105)

While these are clear benefits for the PRC, the other GMS countries also benefit from these investments in trade and tourism; the PRC's cooperation in addressing a variety of cross-border issues, such as human trafficking, regional stability, and development; and increased revenue from the export of their natural resources.[13] For example, from Thailand's perspective, the planned super express rail routes will "turn Thailand into the PRC's gateway to trade with India and Europe…. Beijing has long planned to

[8] The PRC's Minister of Foreign Affairs thought this term, with its military origins, would offend southern neighbors of Yunnan, and wanted to drop it, but it appears in the 12th 5 Year Plan (2011—2015), which was approved by the PRC National People's Congress on 14 March 2011.

[9] In early 2011, Thailand announced that the PRC would construct a major transfer center (warehouses) close to Bangkok's port so the PRC's goods can flow, without tax, into Thailand and out through the port to South Asia and beyond. Kunming is at the north of this North-South Corridor, and Bangkok is at its south. As of 2012, it appears that for the time being, this project has been suspended, if not terminated.

[10] Note that the city of Nanning in Guangxi Zhuang Autonomous Region is also very much connected to the GMS by the transportation infrastructure.

[11] Qin Guangrong, Yunnan's governor stated "the gateway idea has five different forms— as a channel, window, platform, base, and barrier. The channel…means building an international thoroughfare to Southeast and South Asia. The window refers to making Yunnan a showcase of Chinese culture and friendship. The platform means that Yunnan should have an economic and trade cooperation role. The base refers to Yunnan as a manufacture and processing base, while the barrier refers to its role as an ecological barrier." As Qin explained it, "We're going to build international highways, railways, water routes and oil and gas channels and make the city of Ruili a pilot in opening and exploring. It will accelerate economic cooperation as a cross-border economic zone, and take part in building trade and economic cooperation zones beyond the border," Indeed, in 2010, Yunnan's foreign trade increased by a remarkable 69% over 2009 (Li *et al.*, 2011).

[12] The Kunming-Bangkok Highway, completed in April 2008, cut travel time between the two cities from 48 hours to 20 hours. Cooperating with the GMS, the PRC plans to connect to the ASEAN states by way of three rail lines from Kunming through Thailand. Currently, two rail routes—Kunming-Kehou-Hanoi, and Nanning-Ping Xiang-Hanoi—connect the PRC with ASEAN via Viet Nam, but they do not yet connect directly to Thailand. "[T]he PRC's Western Railroad Line will link the PRC with Myanmar, India, and Bangladesh. ….The Nanning-Bangkok Highway via R6, which is under construction, will be the shortest route linking Thailand with the PRC, Viet Nam, the Lao PDR, Malaysia, and Singapore in the near future." As a result, the trade route, which now takes from 8–9 days by sea from the Port of Bangkok to Shanghai, will be shortened to 3–4 days… (*The Nation* (Bangkok), 2011; Lu and Chong, 2010, p. 13).

[13] Others would include sharing benefits (and costs) of water resource development for hydropower, irrigation, and urban use; protection and development of fisheries; environmental protection; protection of water quality; and navigation.

position Thailand as the route linking southern PRC to the Andaman Sea and beyond to South Asia and Europe."[14] Although many Thais have voiced concern about this, the Thailand Government sees significant potential benefits for Bangkok. The planned GMS transport corridors (Figure 1) make clear their benefits to Yunnan Province and Bangkok—and to the entire GMS. Perhaps most important is that water security is itself significantly benefitted by preventing conflict, and China's involvement in the GMS and ASEAN Free Trade Area has contributed to this important aspect of water security.

2.3 Role of Guangxi Zhuang Autonomous Region

Guangxi Zhuang Autonomous Region's relationship with the GMS is different from that of Yunnan, in large part because it is not part of the MRB; so cooperation on issues of water and natural resource sustainability in the MRB are not issues for Guangxi. Originally, Guangxi wanted to join GMS in order to help itself develop. However, the only Southeast Asian country that Guangxi borders is Viet Nam, whereas Yunnan has borders with the Lao PDR,

Figure 1: Planned GMS Transport Corridors

Source: Thailand Ministry of Foreign Affairs, Bangkok, December 2010.

[14] Thailand's Ministry of Finance, as referenced in (Watcharapong, 2011).

Myanmar, and Viet Nam, and is connected by the MRB to Cambodia and Thailand. By 2006, Guangxi decided to pursue development through participation in the Greater (Pan-) Bei Bu Gulf Regional Economic Cooperation [Organization][15] rather than the GMS. This is because, like every Chinese province, it wants a "cooperation" mechanism in which it can play a leading role, in part so that it can get more money for development from the PRC's central Government.

Guangxi desires a leading role in Greater Bei Bu, a role it cannot play in the GMS because Yunnan is much better positioned to lead. As a result, Guangxi's interest in the GMS has diminished, even though it remains a member. There is now considerable overlap in membership of the two groups;[16] but Greater Bei Bu is involved in different projects and engages in trade and commerce along routes that use Guangxi, rather than Yunnan, as the hub (Wong and Chong, 2010).

3. Expanding the Benefits

Geographically, the GMS is larger than the MRB, and the interests of the former are far more comprehensive than just managing the Mekong River system and the natural resources of the MRB. Many of the present benefits in the GMS are the result of bilateral and multilateral deal-making, with the PRC often the primary dealer. Nevertheless, it is the GMS structure, with the institutional support of ADB, that may well prove essential in expanding benefits to all countries in the GMS, and for enhancing cooperation on the very difficult issue of sharing the benefits and costs relating to water, energy, and natural resources development within the MRB.

Inevitably, there are costs associated with the rapid development of the GMS: sustainability, threats to livelihoods, and degradation of the environment. Environmental impact assessments are not often high priority for governments of GMS countries when they make joint or bilateral agreements for investment. In the case of the PRC, this has resulted in complaints and protests from various stakeholders in other GMS countries over Chinese long-term objectives, though rarely from the GMS governments themselves, which are busy making lucrative deals with the Chinese (Asia Times online, 2011). In the MRB, there is a consultative and regulatory role played by the MRC and many stakeholders have been successful in holding up development projects because of the regional nature of this regulatory body. The MRC has helped create peace and stability by developing trust among the MRB countries—trust that other MRB countries cannot act in a way that damages their own state's interests because the MRC will do its best to prevent it.[17]

As mentioned above, almost all development projects in the GMS are bilateral or multilateral and no regional regulatory body is empowered to require consultations concerning the exercise of sovereign rights by its members. Only investors outside the GMS, such as the ADB, which set up the GMS and wants it to succeed, can hold up (or discourage) projects because of sustainability and environmental issues.[18]

4. Conclusions

First, each of the GMS/MRB countries, particularly the larger, wealthier countries in the GMS that are the main investors (PRC, Thailand, and Viet Nam) should consider the whole area not as someone else's land that they can exploit, but rather as their own "backyard"—a place that they actually need and want to protect for everyone's benefit. For example, the Lao PDR and Cambodia already provide outstanding tourism opportunities—with tourists increasingly coming from the PRC, Thailand, and Viet Nam—the three GMS countries that invest most in the GMS. Cambodia and the Lao PDR provide fascinating and beautiful places for citizens of these countries to visit, especially for ecotourism. Outdoor activities—boating, mountain climbing, biking, sight-seeing, and cultural heritage sites are plentiful. So, why do anything that would destroy this natural resource located nearby in another country that their own people would like to enjoy? And, as

[15] (*Fan Bei Bu Wan Qu Jingji Hezhou*—hereafter cited as "Greater Bei Bu")

[16] Greater Bei Bu originally consisted of Guangxi, Hainan Island, Guangdong, and Viet Nam, all places close to or bordering on the Beibu Gulf or South China Sea. Later, it added 8 of the 10 countries in ASEAN (all but Myanmar and the Lao PDR).

[17] The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) in Bangkok supports the MRC because it helps stabilize the whole region by requiring consultation on all projects that affect energy, water, food, and natural resource security and sustainability. (Interview, January 2011) Discussions with other members of the MRC in Vientiane and Phnom Penh suggest, however, that the four countries already in the MRC (Cambodia, the Lao PDR, Thailand, and Viet Nam) are quite hypocritical about their willingness to negotiate or to compromise on issues of national interest.

[18] For example, ADB funds GMS flood management projects that affect MRC work in the MRB; ADB tries to have GMS and MRC cooperate on these issues.

with any non-zero sum game, anything that undercuts the appeal of tourism in one country will impede its growth in the entire region.

Second, the GMS has been successful because it is, in many ways, not addressing the central element of benefit sharing in the MRB, namely, the Mekong River's water. When it comes to sharing or protecting that water as a resource, or sustainably developing water, scientific calculation has in some respects become almost irrelevant, and politics has taken over. As demonstrated in the dispute in 2011 over a small piece of territory on the border of Thailand and Cambodia, where little is at stake compared to control over the Mekong River Basin's flow and natural resources, control over territory and its resources is not something easily settled by a rational cost-benefit analysis.

Third, it is difficult to imagine how there can be poverty reduction without some change, if not damage, to the ecology/environment of the GMS. The MRC and the GMS, with the institutional support of ADB, must find a way to minimize this damage by gaining a more cooperative spirit among the GMS governments. But if nothing is done to control population growth in some of the GMS states, the goal of sustainable development would seem unattainable.

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Annex 1: Discussions and Interviews

Institution	Person	Title
Lao PDR (5–7 January 2011)		
Mekong River Commission	Mr. Jeremy Bird	Chief Executive Officer
	Mr. Ton Lennaerts	Chief Technical Adviser
	Mr. Phetsamone Southalack	Natural Res. Planner/Env. Specialist
	Mr. Voradeth Phonekeo	Project Manager
Lao Ministry of Agriculture and Forestry	Mr. Khamhou Phanthavong	Deputy Director
GHK International	Mr. Victoriano B. Macasaquit	Social and Resettlement Specialist
Cambodia (8-13 January 2011)		
Royal University of Phnom Penh, Department of Environmental Science	Mr. Ham Kimkong	Senior Researcher / Lecturer, Natural Resource Specialist
	Mr. Spoann Vin	Researcher / Lecturer, Urban Environment Management
	Mr. Chann Sopheak	Researcher / Lecturer, Geographic Information System
Virachey National Park	Mr. Chou Sophark	Director
3S Rivers Protection Network (3SPN)	Mr. Paul Humphrey	Information and Advocacy Advisor
Mekong River Commission Cambodia	Mr. Erland D Jensen	Chief Technical Advisor
World Bank	Mr. Veasna Bun	Infrastructure Operations Officer
Thailand (24–29 December 2010)		
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	Ms. Janya Trairat	Water Use Efficiency Division
	Ms. Asdaporn Krairapanond	Director, Office of International Cooperation
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Ministry of Foreign Affairs	Mr. Kasit Piromya	Minister
	Mr. Chavanond Intarakomalyasut	Secretary to the Minister
	Mr. Surasak Suparat	Director, Department of International Organizations, Development Affairs Division
	Ms. Kesarin Phanarangsan	Second Secretary, Department of International Organizations, Development Affairs Division
	Ms. Nitivadee Manitkul	Director, Department of International Economic Affairs, Division of Economic Relations and Cooperation
	Mr. Pornsith Pibulnakarintr	First Secretary, Department of International Economic Affairs, Division of Economic Relations and Cooperation
N-POWER CO., LTD	Dr. Nob Satyasai	President
Thai Oil Public Company Limited (PTT Group)		
People's Republic of China (30 December 2010–4 January 2011)		
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	Dr. Kang Bin	Professor, Asian International Rivers Center

World Wide Fund (WWF) for Nature Beijing Office	Ms. Wu Yusong	Head/Coordinator of UMB Program
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USAID office	Bradford Phillips	Regional Climate Change Adaptation Advisor, Regional Environment Office, Asia
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Renmin University, Beijing	Pang Zhongying	Professor of International Relations and director of Global Governance Studies
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DROUGHT RISK MANAGEMENT AS CLIMATE CHANGE ADAPTATION AND DISASTER RISK REDUCTION LINKAGES IN LOWER MEKONG REGION: ISSUES, CHALLENGES, AND POTENTIAL

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1. Introduction

Climate change has brought new risks to humanity. It is important to understand the nature of these risks, where natural and human systems are most vulnerable, and what may be achieved by adaptive responses. Adaptation to climate change has the potential to substantially reduce many of its adverse impacts by enhancing the capacity of governments and communities to withstand these impacts. While climate change adaptation has been discussed over recent years, including organizational response, little attention has been focused on community adaptation, and integrating community adaptation methods into government policies (Shaw *et al*., 2010a).

Since some of the worst sufferers of climate change are rural communities (Shaw, 2006) whose livelihoods are dependent on agriculture, it is important to focus on the impacts of climate change on their livelihoods and re-establish the links among poverty—defined as stable purchasing power to maintain decent living—livelihood, and environment. However, focusing on communities is not enough; so long as community initiatives do not become part of government policies it is difficult to sustain their efforts, which means that the emphasis should be from both ends. Perhaps the most important prerequisite for creating sustainable livelihoods and for achieving sustainable development is good and accessible government. Thus, the link between local, state, and national governments to the community is of utmost importance.

1.1 Context: Climate Change Adaptation and Disaster Risk Reduction

Schipper and Burton (2009) made an excellent review of the evolution of the term adaptation, from its inception by UNFCCC in 1992. They emphasized that adaptation has a long history in the ecosystem and human sciences, however, it is only recently that, the scientists and growing number of policy makers have begun to grapple with how humanity can actually adapt in a planned and strategic way as climate changes. Schipper and Burton (2009) gave a logical flow between theory, definitions of vulnerability, resilience, relation to disaster risks, development, and linkage to climate change policy.

Leary *et al.* (2008) stated that adaptation can be a specific action (e.g., a farmer switching one crop to another), systematic change (e.g., diversifying rural livelihoods), or an institutional reform (revisiting water reform and land ownership). Adaptation can be product as well as process. Leary *et al*. (2008) argued adaptation to be a process, which includes learning about risk, evaluating response options, creating the conditions that enhance adaption, mobilizing resources, implementation, and reviewing choices with new learning.

Climate change adaptation (CCA) and disaster risk reduction (DRR), though broadly understood to be linked in some ways, have not yet been taken as a holistic set of actions that require collaborative and coordinated action by all concerned stakeholders (Shaw *et al*., 2010a). The significance of CCA-DRR synergy is felt most by vulnerable communities who do not feel the impact of climate change or natural disasters sectorally, but as a combined whole with devastating effects. Thus, a sectorally split approach to this complex set of problems will not bear fruit. Recent work by researchers and policy makers has thrown light on the intricate linkages between cross-sectoral development activities, their impact on the environment, subsequent detrimental impacts of a deteriorating environment on human life, and the integrated approach needed to address this combined threat of climate change and disasters (AUEDM, 2010). Such an understanding can be very meaningfully deployed at various levels from governance to voluntary action to education, and can go a long way in developing community-based and environment-based resilience to climate change as well as disasters. CCA began to receive attention in 2005 in COP 11, which prepared the Nairobi Action Plan (Shaw *et al*., 2010a). Further attention and commitments were gained in 2007 in the Bali Road Map and Action Plan, followed by COP 15 in 2009, but a consensus exists that CCA is more talk than action. Local implementation of adaptation policy is considered to be the core of success of adaptation.

DRR evolution showed a similar trend. In the 1960s and 1970s, disasters were generally thought to be extreme events and the focus was more on relief and

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rescue, dominated by civil defense and the Red Cross. Due to strong lobbying of professional societies like the International Association of Earthquake Engineering, the United Nations (UN) designated 1990 to 1999 as the International Decade of Natural Disaster Reduction. Two major events brought DRR into prominence: the 1994 Yokohama World Conference on Disaster Reduction and the 1995 Hanshin Awaji earthquake of Kobe, Japan. A strong need for a multidisciplinary approach was felt, which emphasized the focus on local rather than national approaches. In 2000, the UN International Strategy for Disaster Reduction (ISDR) took the charge of international advocacy and negotiations in this field. The 2004 Indian Ocean tsunami brought the disaster issue into high political profile and in 2005, the UN member states signed the Hyogo Framework for Action (HFA: 2005–2015). Development agencies also expressed their commitments by establishing the Global Facility for Disaster Reduction and Recovery with its secretariat at the World Bank, and incorporating disaster-related issues in development activities.

A recent compilation demonstrated the linkages between climate change adaptation and disaster risk reduction in two volumes that describe the issues and challenges and Asian experiences, respectively (Shaw *et al*., 2010b).

1.2 Common Issues and Challenges of CCA and DRR

Three common issues of CCA and DRR development are: increasing focus on local governments, emphasis on multidisciplinary approaches, and emphasis on theory to practice. The key challenge is how to incorporate CCA and DRR in local practices (Shaw *et al*., 2010a).

CCA and DRR do not fully overlap. However, there is scope to bring the two sectors together. One of the key differences is that DRR approaches are mainly based on past experiences, while CCA is based more on future projections. For example, when a river dyke is made as a DRR measure, the deciding factors for the height of the dyke are past flood levels or rainfall data, and importance of the area (commercial, residential, industrial, or agriculture). This has been a traditional approach of DRR. However, the current DRR approach incorporates possible future rainfall in the area (with different levels of uncertainty), in addition to the above factors. This is an example where CCA and DRR come together. Adaptation can be planned (with information on future uncertainty) or autonomous (without focusing on long-term future). Understanding adaptation depends on two key parameters: clarity or uncertainty of existing climate predictions and the vulnerability of a community or household to a given climate-related hazard. After examining uncertainty and vulnerability in more detail, the elements of adaptation are considered, with particular emphasis given to the role played by social networks in enabling knowledge sharing, access to resources and influence over policy. The principal adaptation activities are identified as vulnerability reduction, building adaptive capacity and strengthening resilience (Ensor and Berger, 2009).

Several activities are considered useful to contribute to resilience and adaptive capacity of communities (UNDP, 2002): diversification of livelihood activities, assets, and financial resources; mobility and communication (ability of goods, people, information and services); ecosystem maintenance (with basic services like water); organization (social networks, organizations, institutional systems); adapted infrastructure (physical structures for basic services); skills and knowledge (ability to learn and basic educational skills); asset convertibility (development of assets or markets); and hazard-specific risk reduction (early warning, spatial planning, building codes, etc.). UNDP (2002) also noted that governance plays an important role in bringing CCA and DRR closer together. Social, political, and economic systems that deny groups access to key decision making are also considered important. Adger *et al*. (2009) emphasized three challenges of adaptation: ecosystem and sociological systems absorbing the perturbation as adaptation, values of adaptation (from different perspective) to be included properly in decision making, and the governance dimension of adaptation.

Leary *et al*. (2008) listed nine adaptation lessons: need for adaptation action now, create conditions to enable adaptation, integrate adaptation with development, increase awareness and knowledge, strengthen institutions, protect natural resources, provide financial assistance, involve those at risk, and use place-specific strategies. The same lessons are equally applicable to the DRR field, when it is seen through the lens of Hyogo Framework for Action (HFA, 2005): ensure that DRR is a national and a local priority with a strong institutional basis for implementation (institutional issue); identify, assess, and monitor disaster risks and enhance early warning (risk assessment); use knowledge, innovation, and education to build a culture of safety and resilience at all levels (education); reduce the underlying risk factors (links to development); and strengthen disaster preparedness for effective response at all levels (emergency response).

1.3. The Context: Lower Mekong Basin

The lower Mekong River Basin (MRB) is located in the East Asian Monsoon region, which affects large parts of the People's Republic of China (PRC), Indo-China, Japan, Republic of Korea, and the Philippines. It is characterized by a warm, rainy summer monsoon and a cold, dry winter monsoon. The rain occurs in a concentrated belt that stretches east-west except in the eastern PRC where it is tilted east-northeast over Japan and the Republic of Korea. The onset of the summer monsoon is marked by a period of pre-monsoonal rain over the southern PRC and Taipei, China in early May. From May through August, the summer monsoon shifts through a series of dry and rainy phases as the rain belt moves northward, beginning over Indochina and the South China Sea (May), to the Yangtze River Basin and Japan (June) and finally to northern PRC and the Republic of Korea (July). When the monsoon ends in August, the rain belt moves back to the southern PRC (Shaw *et al*., 2010).

The lower MRB plays an important role in the well-being of Cambodia, PRC, Lao PDR, Myanmar, Thailand, and Viet Nam as the Mekong is the major river supporting agriculture and many other economic activities in the region (Figure 1). The lower MRB is also a cause of concern due to the regular floods it brings, which have a significant impact on the lives of many people in the river basin. However, in recent times, the MRB has become increasingly vulnerable to drought. A notable example was the drought of 2004, which began two years earlier and grew to serious proportions. Dealing with drought requires strategies different from those for dealing with floods and typhoons, which have plagued the Mekong region for years. Local communities, governments, and nongovernment organizations (NGOs) know how to deal with these age-old problems but drought, being a slow-onset disaster with crippling impacts, needs to be looked at from a different perspective.

Figure 1: Map of Lower Mekong River Basin

Source: http://www.mekongboat.com/mekong_map.htm

2. Droughts in the Lower Mekong Region: an Interplay of Climate Change and Disasters

Drought is a slow onset disaster and it is not an unusual occurrence (Wilhite, 2000). For several years, the Asian monsoon countries suffered under a long-lasting severe drought, until the wet 2010 El Niño-driven winter and spring. The impacts of drought are non-structural—unlike other hydro-meteorological extremes, such as floods and typhoons—and they tend to be much more widespread geographically. The severity of a drought is dependent not only on its duration, intensity, and spatial extent, but also on the specific environmental and economic activities carried out within it. Once a drought is established, economic, social, and environmental consequences pose a serious threat to those who rely on secure water availability and supplies, including farmers, fishers, and households. Vulnerability is further aggravated by population growth and migration, urbanization, land-use changes, government policies, water use patterns, the diversity of income generating activities, changing cultural practices, etc. Therefore, it is useful to discuss and agree on definitions and indicators.

The Asian monsoon region has rice farming as a basis for food production. Agriculture is very diverse from north to south, and the countries are characterized by high biodiversity around rice fields. Drought affects mainly rural livelihoods and causes rural migration (Shaw *et al*., 2007). For example, millions of farmers and low-income earners were affected by the drought of 2004, which

caused considerable agricultural losses in Cambodia and northeastern Thailand, significant reduction in the second rice crop in the Lao PDR, and critical levels of saline intrusion in the Mekong Delta (Navuth, 2007). There are four main types of droughts, described in Table 1.

2.1. Meteorological Droughts

Drought events in the Mekong Basin have occurred several times in recent years (to 2004)—in 1992, 1993, 1998, and 1999 (MRC, 2005). The 1993 and 1999 events extended across every region of Thailand and caused water shortages within the agriculture, industrial, and domestic sectors. The 1998 drought was also severe, especially in the Mekong Delta of Cambodia and Viet Nam. Flood season flows were low, with critically reduced flood plain inundation. Tonle Sap, the Great Lake, recorded a maximum level of only 6.85 meters (m) and a flooded area 7,000 square kilometers (km^2), compared to typical seasonal maxima of 8–9 m and 15,000 km^2. In six provinces of the central highlands in Viet Nam stretching 400 km south from Hue, severe meteorological and agricultural drought was reported.

The most recent drought event began in 2003 and generally lasted into 2005, although there are some areas where lower than normal water levels and flows are still being observed. Close and routine monitoring in these areas is being carried out by concerned national line agencies and the Mekong River Commission (MRC) Secretariat. The most recent regional drought episode emphasized the point drought is not just about accumulated rainfall deficits, but also about unexpected patterns of rainfall occurrence.

Regionally, total rainfall in 2004 was average, but it all occurred early in the monsoon season, which ended very early in the first weeks of September, after which rainfall was only a fraction of normal. Mean regional rainfall over the lower MRB during the last quarter of 2004 was only +/- 47% of normal. Among the four countries, Thailand received only 13% of the normal amount 29%, 65%, and 68% were the equivalent figures in Lao PDR, Viet Nam, and Cambodia, respectively (Nguyen, 2010).

The current water level on the mainstream Mekong River is significantly below average in northern Lao PDR and Thailand. Levels at mainstream measuring stations at Chiang Saen, Chiang Khan, Luang Prabang, Vientiane, and Nong Khai are below those that occurred in the low flow season of 1993, which followed the most extreme regional drought on record in 1992. All mainstream water levels measured north of Stung Treng are significantly below the average for this time of year and are expected to decrease further for another month. Starting from that low base, analysis of the rainfall at selected hydrological stations in Yunnan, Chiang Saen, and Luang Prabang has shown a consistent pattern of monthly precipitation significantly below average amounts since September 2009. For example the rainfall recorded at Chiang Saen in November and December 2009 was only 20 mm compared to the long-term average of 52 mm for the same

Table 1: Characteristics of Four Types of Drought

Type of drought	Characteristics
Meteorological	Meteorological drought is the amount of dryness and the duration of the dry period. Atmospheric conditions that result in deficiencies of precipitation change from area to area.
Hydrological	Hydrological drought is associated with the effects of low rainfall on water supply. Water in hydrologic storage systems, such as reservoirs and rivers, are often used for multiple purposes, such as flood control, irrigation, recreation, navigation, hydropower, and wildlife habitat. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly.
Agricultural	Agricultural drought mainly effects food production and farming through soil water deficits, reduced groundwater or reservoir levels, etc. Deficient topsoil moisture at planting may stop germination, leading to low plant populations.
Socioeconomic	Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Due to variability of climate, water supply is not satisfactory to meet human and environmental needs in some years. The demand for economic goods is increasing as a result of increasing population. Supply may also increase because of improved production efficiency and technology.

Source: Shaw *et al.* (2011).

period and this has contributed to the low river flow. The very low water levels recorded at monitoring stations in the mainstream between Chiang Saen and Nong Khai show that tributaries in the Lao PDR and Thailand are not feeding as much water into the mainstream as would be expected. This can be seen with the Nam Khan River that flows into the Mekong at Luang Prabang. Water levels in the Nam Khan are the lowest for 50 years.

The implications of these low water levels are serious for the people of the northern Lao PDR and Thailand. Severe drought will have an impact on agriculture, food security, access to clean water, and river transport and will affect the economic development of people already facing serious poverty. The northern provinces are amongst the poorest areas for both the Lao PDR and Thailand. River tour operators have stopped offering services on the stretch of river between Houiesay and Luang Prabang and it has been reported that Yunnan provincial authorities have halted the operation of Chinese cargo boats, which will affect regional trade. The National Centre for Environmental Health and Water Supply in the Lao PDR has started advising people to counter the effects of drought by reducing water consumption. The MRC is undertaking more detailed assessments of the low flow conditions and is working with its member countries to closely monitor the drought situation as well as integrating drought management considerations into its climate change adaptation initiative.

The drought vulnerability of a region can be assessed using the Standard Precipitation Index (SPI). The SPI is the difference of precipitation from the mean for a specified time period divided by the standard deviation where the mean and standard deviation are determined from past records. However, as the precipitation will not be normally distributed over the time scale considered, a transformation is applied to the distribution. The SPI is simply the transformation of the precipitation time series into a standardized normal distribution. Following are examples from countries in the region:

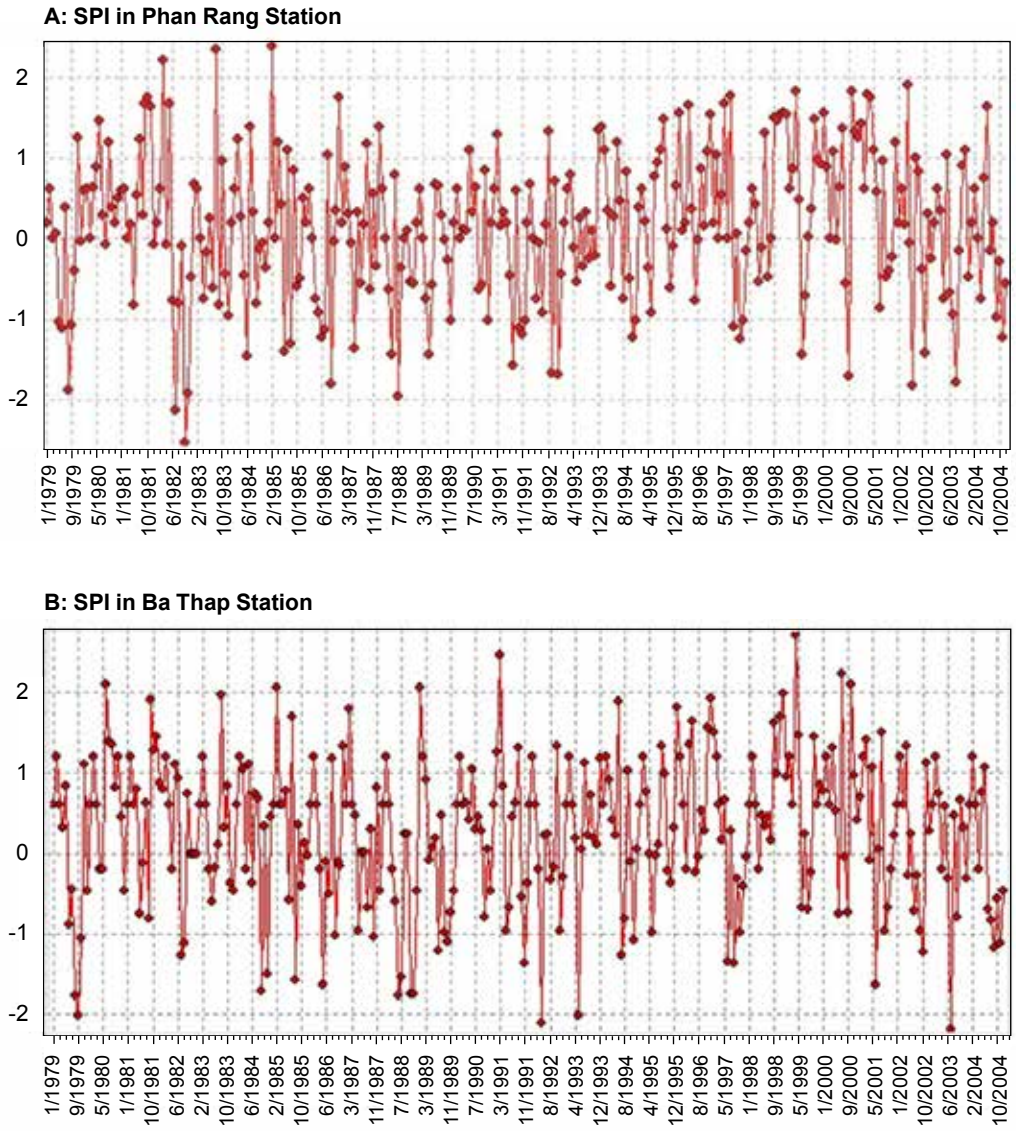
Viet Nam. According to the data from national drought research (Hoc, 2002), drought events were identified based on the drought index, which uses hydro-meteorological data in order to indicate meteorological drought. The evidence of climatic data shows that rainfall and temperature are increasing in the lower Mekong region in recent decades. This provides more evidence the change of global climate (IPCC, 2001) and the prediction of the Viet Nam Hydro-Meteorological Institute (1999). The climate is changing in south central Viet Nam with variations of rainfall and temperature. Droughts occur because of the change in rainfall pattern and very low precipitation in this area. The analysis of available meteorological data through SPI indicated high variability in rainfall, which is the reason for prolonged meteorological droughts. It is recorded that there were 19 drought years in Phan Rang and 17 drought years in Ba Thap within 26 years.

Here, the SPI was calculated using average monthly precipitation in 2 stations in Ninh Thuan Province. The SPI time series spanning January 1979 to December 2004 in the 2 catchments Phan-Rang and Ba-Thap are presented in Figure 2, which shows that SPI values vary significantly, temporally and spatially, reflecting the fact that rainfall in Ninh Thuan Province is not only influenced by large-scale atmospheric circulation but also by local weather regimes. The SPI values illustrate dry and wet conditions well. They correspond well to statistical records of drought occurrence in 19 years during 1979 to 2004 in Phan Rang. Severe drought events occurred in 1979, 1982, 1986, 1988, 1991, 1992, 2000, 2002, 2003, and 2004. The data recorded in Ba Thap station show that there have been 17 drought years with 10 severe drought years, namely, 1979, 1984, 1985, 1986, 1988, 1992, 1993, 2001, 2003, and 2004.

Figure 2 includes SPI values during some severe drought years in Ninh Thuan Province. Most SPI values are negative during these years. A large-scale drought occurred from early spring to end of summer in 1998 corresponding to highly negative SPI values, and it had severe impacts on socioeconomic conditions. Thus, the SPI is a good indicator of occurrence, intensity, and magnitude of meteorological droughts based on precipitation records. Therefore, it can be used for drought monitoring and assessment in the south central coast of Viet Nam.

Cambodia. The rainfall data obtained from Svay Rieng Province was subjected to SPI analysis and results as presented in Figure 3. The figure indicates that there has been a large deviation of rainfall over the study period. Out of 282 rainfall events (monthly rainfall data), 126 (42%) events were negative (lower than the normal), and 172 were higher than normal. We counted the maximum consecutive negative months between January 1982 and November 2006. Six consecutive negative SPI values occurred during the 50 months of January 1982–January 1986 followed by 5 consecutive negative SPI values during May 1998 to May 2002. During the study period, a maximum SPI value of 2.78 and a minimum SPI value

Figure 2: Time Series of Monthly Standard Precipitation Index (SPI) Values in Two Stations in Ninh Thuan Province, January 1979–December 2004



Source: Nguyen (2010).

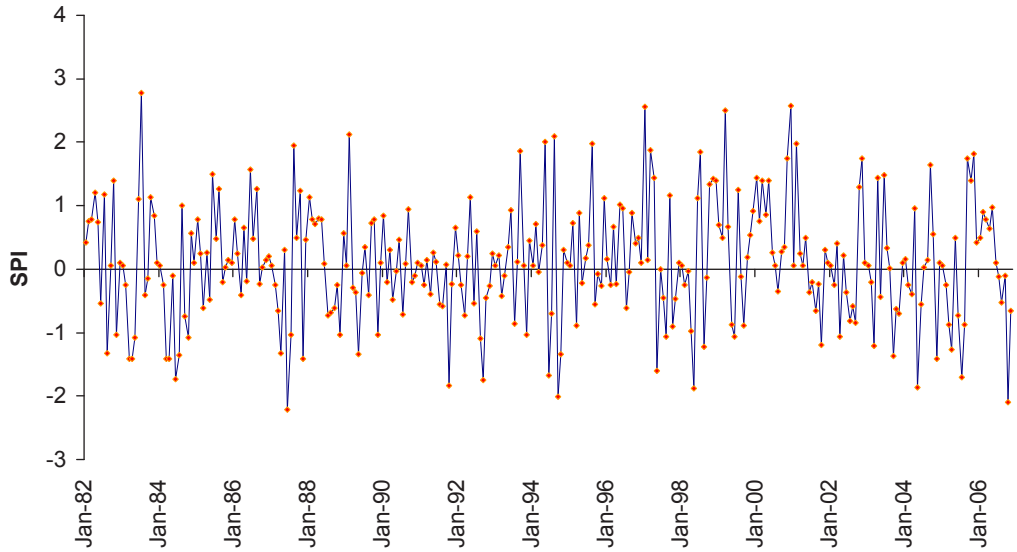
of -2.21 were recorded. In 2002, the year of drought in Cambodia, six negative SPI months were recorded (Figure 3). The months of June, July, August and September—the months of the southwest monsoon—had negative SPI values; the monsoon revival in October and November was indicated by positive SPI values.

From the above observed behavior of drought in Cambodia, it can be recognized that rainfall in Svay Rieng is erratic with detrimentally long dry spells spanning 6 months at times. This necessitates dependable irrigation, water harvesting, and storage systems so that crop production is not severely hampered due to water scarcity.

Thailand. Northeastern Thailand has been frequently subjected to drought, although the amount of rainfall is relatively high. The major causes are erratic distribution of rainfall—dry spells in the rainy season from June to July and also in last two weeks of September, and low water-holding capacity of soil. The most serious negative result from drought is water deficiency for agriculture, the major economic sector in the region, which impacts human life, property, and agricultural production in the region and the country as a whole (Wattanakij *et al*., 2007).

Annual rainfall of the region ranged from a minimum of 778.25 mm in the southwest to a maximum of 3,021.50

Figure 3: Standard Precipitation Index of Rainfall Events in Svay Rieng during 1982–2006



Source: Nguyen *et al.* (2009).

mm in the northeast. Rainfall in September and October in the northeast comes from the northeast monsoon and the amount of rainfall is higher than in the southwest. Over 70% of the northeast receives annually 983–1,437 mm. of rainfall, while the areas along the Mekong River receive 1,437–2,345 mm. The spatial autocorrelation of rainfall in the study area was examined from a semivariogram and covariance cloud (Wattanakij *et al*., 2007).

Analysis of spatial pattern of drought using spatial SPI and temporal SPI from rainfall data was used to determine the spatial distribution of drought and evaluate drought affected areas and drought frequency in northeastern Thailand. The spatial pattern of mean annual rainfall over 29 years was confirmed to increase from the southwest to the northeast. A measurement of reliability of rainfall at each station for the study periods using covariant analysis indicated high values at 6 months and 12 months in the western part of the region. Multi-temporal SPI analysis at various time scales was used to indicate drought occurrences at the station and their severity. From the observation of decadal variation of rainfall since 1976, shown by values of SPI < -1, it was indicated that drought in the region was more severe during 1988 to 1999. The most affected areas were the western and southern parts and its severity, which is associated with the pattern of rainfall, decreased from southwest to northeast. The worst dry years from spatial SPI were 1979, 1981, 1986, 1997, and 2001. The frequency, area extent, and severity of drought as assessed from SPI could benefit sustainable water resources management and the development of mitigation strategies of drought events in the region (Wattanakij *et al*., 2007).

The Lao PDR. In the upper part of the lower Mekong Basin, the rainfall from July 2009 to February 2010 was comparable to the long-term average. However, from September onwards rainfall was considerably less than normal.

From these preliminary rainfall data, the indications are that the 2009 monsoon in Southeast Asia ended early. The average date for monsoon withdrawal at Chiang Saen is the first week of November and at Vientiane the first week of October. The early withdrawal of the monsoon in 2009 meant that the discharges on the Mekong and its northern tributaries started to recede early in the season, drawing on the available natural catchment and groundwater resources. Catchment and groundwater storage in the northern parts of the basin is not large, so a deficit situation would have arisen relatively quickly, particularly in the large tributaries in the northern Lao PDR, leading to considerably reduced flow contributions to the mainstream.

2.2. Agricultural and Hydrological Drought

In the lower MRB, the definition of drought is based on its impact on water resources (hydrological drought) and agriculture (agricultural drought). Agricultural drought is effectively just a concept, which reflects the perspective

of the agricultural sector on water shortages. This concept links the lack of precipitation (or river flow or groundwater) to agricultural impacts. Crop water requirements depend on local weather conditions, soil and plant characteristics, and plant stage of growth. The extent of an agricultural drought should ideally be defined in terms of its impact on a specific plant on a specific soil in a specific area, which makes it a difficult task to accomplish. In more general terms, agricultural drought exists when root-zone soil moisture is insufficient to sustain crops between rainfall events. In this context, the status of soil water deficit in the top meter of a soil profile may be used as a drought measure. In practical terms, some of the indices referred to above are used to monitor the developing deficits of water availability to crops. Hydrological (flow and groundwater) drought is the effect of low precipitation on hydrological systems. In some cases, the impact on both rivers and aquifers is included under this "type". In other cases "a flow drought" is distinguished" from "groundwater drought". In both cases, a hydrological drought usually lags behind the deficient precipitation. It takes longer for precipitation deficiencies to manifest themselves through the river flow or through the groundwater level.

The history of drought events in MRB indicates that drought has occurred throughout Viet Nam, in southern Thailand, the central region of the Lao PDR, and in southern Cambodia. Observations have also indicated that the frequency of drought in the region has been increasing in recent years. A deficit of rainfall over a certain period in combination with high temperature and high potential evaporation may lead to huge deficiencies in water supply over the region, which subsequently may turn into a large-scale drought with impacts on the water-using sectors, e.g., losses in agricultural production, emerging forest fires, and reservoir depletion, as well as on related sectors causing, e.g., famine, diseases, and conflicts.

This decrease in upstream water levels is reflected at Luang Prabang and Vientiane from late January onwards. Clearly, the contributions from the large northern Lao PDR tributaries, such as the Nam Ou and Nam Khan, were already low due to the drought conditions; observations confirm that these rivers are currently very low.

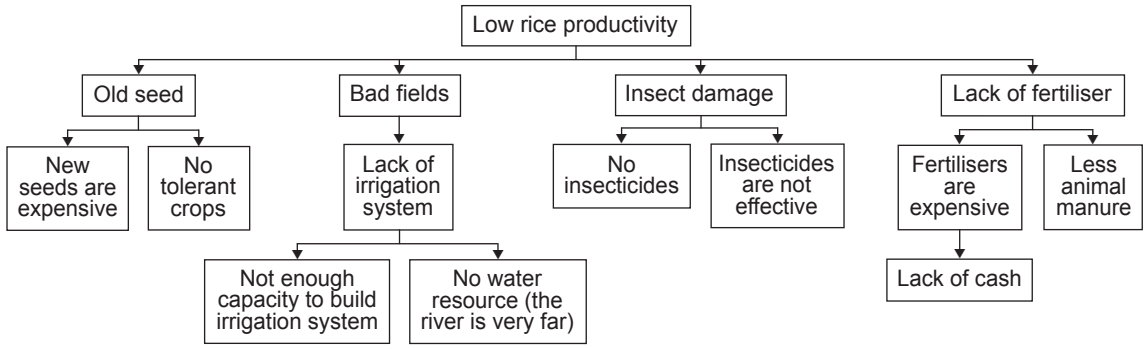
Further downstream at Kratie, the decrease in water levels during February remains quite apparent, with those of 2010 being half a meter higher than those of 1993 during late February. Water levels in the Mekong River at Chiang Saen from November 2009 onwards were higher than those in 1992-93. At Luang Prabang and Vientiane, the opposite is the case. This suggests that the water levels at Chiang Saen were kept artificially high by upstream reservoir releases until late January when they receded. The levels at Luang Prabang and Vientiane being lower than 1992-93 reflect the regional drought conditions from September 2009 onwards and the very low contributions to the mainstream by the large tributaries in the northern Lao PDR. The situation represents serious regional hydrological drought conditions.

3. Drought Risk Reduction Approaches

As vulnerability to drought has increased globally, greater attention has been directed to reducing risks associated with its occurrence through the introduction of planning to improve operational capabilities (i.e., climate and water supply monitoring, building institutional capacity) and mitigation measures that are aimed at reducing drought impacts. This change in emphasis is long overdue. Reducing the effects of drought requires the use of all components of the cycle of disaster management, rather than only the crisis management portion of this cycle. In the past, when a natural hazard event and resultant disaster has occurred, governments have followed with impact assessment, response, recovery, and reconstruction activities to return the region or locality to its pre-disaster state (Wilhite *et al*., 2002, 2005). Little attention has been given to preparedness, mitigation, and prediction/early warning actions that could reduce future impacts and lessen the need for government intervention in the future. Because of this emphasis on crisis management, society has generally moved from one disaster to another with little, if any, reduction in risk. In fact, many response measures instituted by governments, international organizations, and donors have actually increased vulnerability by increasing dependency on internal or external assistance. All components of the cycle of disaster management should be addressed in a comprehensive hazard mitigation plan, but greater attention than in the past needs to be placed on pre-disaster activities.

In this section, one example is brought from Viet Nam, introducing a policy for drought risk management at national and community levels. The root causes of drought problems were identified at the local level. Impact tree diagrams were constructed and root causes were uncovered through probing questions, such as 'why lack of water?' Local communities were asked to provide their problems during the drought events and the main problems were chosen to identify the root-causes (Figure 4).

Figure 4: An Impact Tree Diagram for Agriculture



Source: Nguyen (2010).

Based on the root causes, policy options were identified for DRR that could be implemented by governments, NGOs, and communities. Emphasis was given to identify a mix of policy options containing mitigation and response strategies. For example, provision of more microfinance to provide financial capital, enhancing weather monitoring and forecasting for better drought preparedness, and regulations to restrict water use through strict irrigation scheduling and water distribution to solve the problem of bad practice on water use and water management. The actions taken will depend on needs, local conditions, and other resources.

3.1. National Drought Strategy

A drought policy should encompass responsibilities and obligations from the government to the local level and especially citizens affected by droughts. Promulgating a drought policy is fundamental to determining technical norms and assistance to reduce the impacts of droughts through relevant and legal actions, e.g., aid programs, healthcare, low interest loans, and subsidies. A set of generic responses to drought was developed by Wilhite (1991):

- Establish a specialized drought task force.
- Organize stakeholders to participate in the preparation and implementation of measures and resolution of conflicts.
- Unify techniques and policy at all levels.
- Determine the drought risk in order to prepare actions for risk mitigation, and minimize difficulties after a drought occurrence.
- Monitor and assess the implementation of drought mitigation and response measures, including mistakes and successes to meet the demand of social and economic development.
- Promulgate drought plans and carry out timely public awareness campaigns.
- Enhance participation in actions for drought mitigation and response processes.

Crucially, those most at risk from drought risk and climate change, the rural poor, have limited information or financial and technical support to adapt to their changing world, despite some localized successes. Their direct experience of drought risk and climate change impacts should be incorporated into future responses, and solutions sought that build on existing local adaptation practices, where appropriate. The people who are directly affected by drought and other disasters and climate change should also be key participants in the planning and implementation of future climate change adaptation measures, particularly where these require relocation or significant dislocation of existing livelihood practices.

A national drought committee is needed to to supervise and coordinate development of drought planning corresponding to the multidisciplinary nature of drought and its impacts. During drought occurrence, the drought committee should work closely with public media to keep the public well informed of the water supply status and drought condition that may lead to requests for voluntary or mandatory use restrictions. The committee should have access to assistance from other government agencies and organizations, including international organizations and NGOs.

3.2. Drought Strategy at Local Government Level

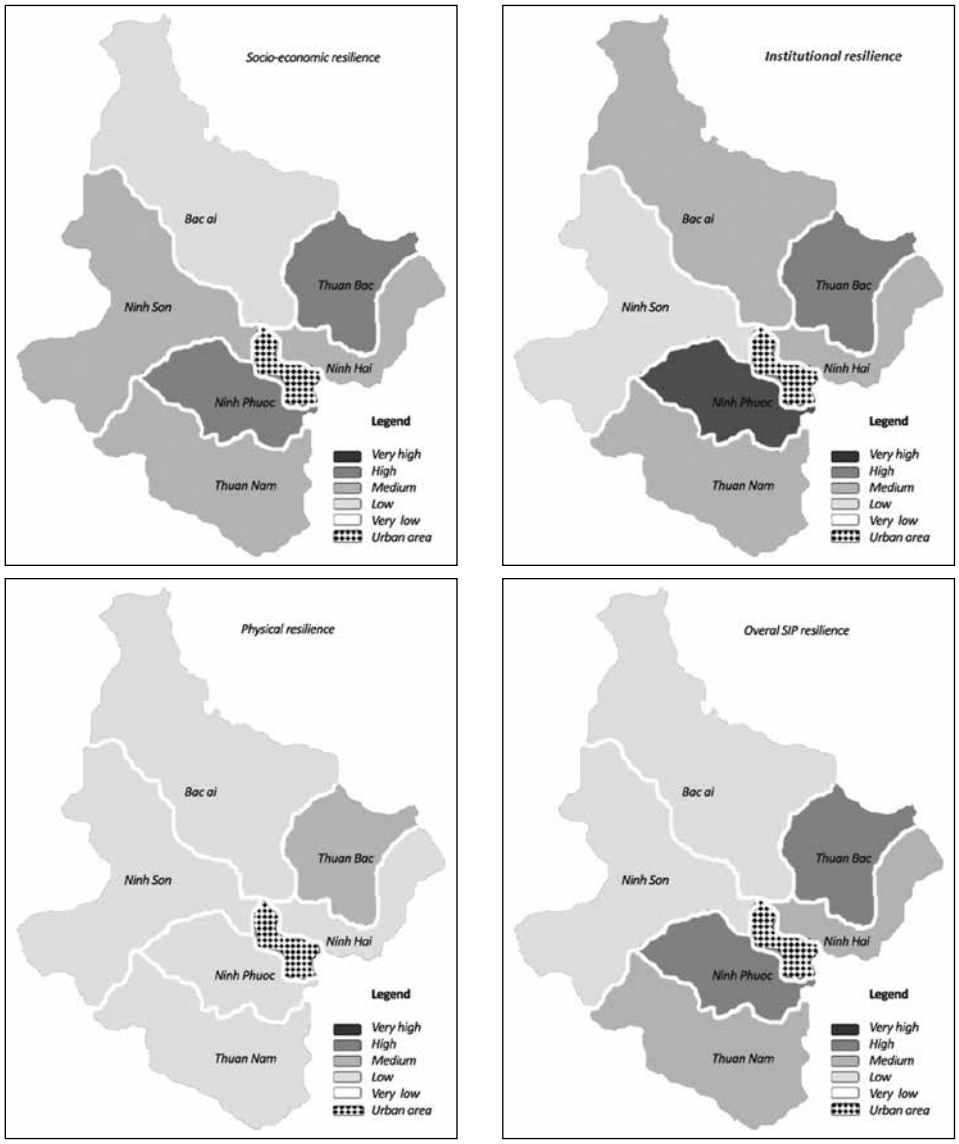
Local governments also include entities other than the drought community, e.g., county government offices. Local governments may assist in drought management in the following ways:

Assist With Planning. Assist the drought community within their jurisdictions to plan and coordinate the development of water supplies, extension of infrastructure, and the coordination of resources, manpower, and technical expertise. Assist the community water system in the development of the drought management plan.

Implement Drought Responses. Local government officials involved in the development of the drought management plan will be informed about the trigger-points for the various drought phases and the planned responses. The local government may be able to assist in the implementation of some of those responses, especially those associated with emergency conditions. For instance, in certain phases of drought, local governments may be tasked to haul water for domestic and livestock.

Mainstream Sustainable Land Management into Provincial Frameworks. Mainstreaming is a two-pronged approach of embedding development concepts into the provincial plans while also effecting changes in the way of doing business, e.g., policy reforms, changes in planning, institutional structures, and coordination arrangements. It leads to increased recognition of the importance of land management in development and could increase investments by the public budget and international financial contributions.

Figure 5: Socioeconomic, Institutional, and Physical aspects (SIP) Resilience Mapping of Ninh Thuan Province



Source: Nguyen and Shaw (2011).

Resilience Mapping. Resilience against droughts and dry spells is fundamental for water security. Resilience (as it applies to integrated systems of people and nature) is the amount of change a system can undergo (e.g., land degradation) and still remain within the same state (e.g., avoid desertification by continuing to produce essentially the same ecosystem services). With regard to drought resilience issue, the socioeconomic, institutional, and physical aspects (SIP) approach was developed to determine different SIP aspects of a targeted area and provide an overview of drought resilience of that area. The approach helps to find out the strength and weakness of the three dimensions for drought resilience. Government and different organizations can prioritize a sector and provide inputs for the formulation of policy that will help to minimize the drought risk (Habiba *et al*., 2011).

Each SIP dimension has several primary indicators and each primary indicator has five secondary indicators. A questionnaire survey is the primary tool for data collection. The quality of the results is very much dependent on proper understanding of the questionnaire. The results are qualitative and serve mainly to give better understanding of drought resilience of the study area. Figure 5 shows resilience mapping of Ninh Thuan Province, which can be used as a decision tool at the local level.

3.3. Implementation at the Community Level

The local community should be involved in the process of drought risk management by establishing a "drought community" in each commune where drought frequently occurs.

Role of the Drought Community. The drought community can contribute to the process of drought early warning and forecasting. Local people can observe and predict weather by their traditional knowledge of changes in plants and animals, influence of the moon and sun, the dryness of their fields, etc. Their information can be combined with climate data for drought early warning analysis. The local community, via its associations, then receives the drought early warning information directly from a provincial hydro-meteorological center. The drought management plan should provide equitable drought protection to the community. Development of the plan may provide the community water system with an opportunity to establish their priorities and identify the means to meet this priority.

For these reasons, a drought management plan is often a companion to a regional water supply plan. Communities that conduct effective regional supply planning find that there is less need for drought management planning. In assessing their risk, a drought community often finds that the best drought preparation is developing interconnections with other facilities to form a regional water system and improve the adequacy of their sources.

Drought Proofing. For practical measures, some appropriate approaches, as shown in Table 2, should be considered for drought risk management. Some of these measures are outlined below.

Fodder Banks. Farmers need to provide their animals with quality feeds to augment dry season forages, especially if there is the prospect of coming drought. One option is to supply expensive concentrates or supplemental feeding. For most small-scale farmers this is not possible due to the high cost and limited availability of supplements. A more practical option is for farmers to establish fodder banks, plantings of high-quality fodder species. These can be utilized all year, but are designed to bridge the forage scarcity of annual dry seasons.

Microcredit. The rural poor generally do not have the capacity to start income-generating activities due to lack of financial capital (Ahmed, 2004). They also have very limited access to the formal financial institutions because of the inability to fulfill the collateral requirements. Thus, microcredit programs have been launched which require no collateral to obtain loans. Their major goal is to provide financial capital to the rural poor in order to engage them

Table 2: Drought-Proofing Measures at Individual, Community, and Local Government Levels

Dimension	Individual	Community	Local government
Environmental impact	- Water use management	- Community-based forest management - Community-based water management	- Reforestation - Land-use management
Social impact	- Lifestyles	- Lifestyles	- Heath care service - Education
Economic impact	- Livelihood diversification	- Fodder bank - Microcredit - Livelihood diversification	- Irrigation system - Water management - Livelihood diversification

Rice Straw for Cattle and Sheep at a Household in Ninh Thuan Province, Viet Nam

in income-generating activities for alleviating their poverty (Mahmud, 2006). Microcredit can help them to recover from drought and perhaps diversify into enterprises less likely to be affected by drought.

Ecological Planning. The target of ecological planning is to set up a sustainable system of local practices for DRR in drought-prone areas. This brings benefit not only for local people but also for the environment. In the lower MRB, agricultural systems concentrate on a limited number of crops, such as rice, maize, cassava, sugar cane, onion, garlic, and soy beans, as well as raising sheep, goats and cattle. Most farms use monoculture, but some use multicropping or agroforestry systems.

With relation to temperature, it is predicted that an increase of 1.6 degree C will be experienced in the next 50 years and average annual rainfall will increase by 2.7% in the region. Although annual rainfall is increasing there is no corresponding increase in water availability due to high run off, low infiltration and high evaporation. The impacts of climate variability are taking their toll on local communities as they are experiencing reduced income due to increased mortality of crops from heat and water stress; reduced productivity of livestock due to declining fodder availability and heat stress; ground water subsidence due to over extraction and saline intrusion in coastal areas (contamination of wells); and increased “natural” disasters such as droughts and floods.

The farm households better adapted to the natural ecological constraints of the region and increasing climate variability are those who pursue an agro-silvopastoral system supplemented with small water harvesting structures. This system combines the following: a blend of annual subsistence and market crops both shade grown and under sunlight; fruit, fodder, leguminous and high value trees (perennials); citrus and other medium height bushes or shrubs; stall-fed livestock; and small-scale rainwater harvesting structures. From an adaptation to climate change perspective, the main challenge to be overcome in reducing the vulnerability of local communities is to be able to facilitate a shift from a high water-use mono-crop production system to the adoption of integrated eco-farming models that generate a diversity of products. The key constraints identified in making this shift are the following: i) Inadequate institutional responses with regard to land-use planning and management, ii) an effective regulatory framework that protects investments, and incentive frameworks to support integrated eco-farming systems; iii) Focus on short-term gains over longer term sustained benefits; iv) Cultural norms and values associated with existing cultivation practices (in many cases highly unsustainable) and a lack of knowledge and skills for adopting alternative integrated eco-farming models; v)Insufficient inventory of crop, shrub, bush, tree and livestock varieties suitable for the ecological conditions of the region that have market value; and vi) Insufficient capture of value addition and market access.

For the drought prone areas, it is evident that tree and vegetative cover on farm lands need to be increased considering the multiple characteristics trees exhibit and benefits that they provide, such as, ability to tap ground water; low maintenance after the first few years; produce high value products for the market and subsidiary products like fodder, fuel wood and small construction material; increase leaf litter and soil fertility; decrease soil erosion by forming wind breaks and mitigating rainfall intensity; moderating heat stress by increasing shade cover; and increasing biodiversity. The adaptive agriculture program integrated with other programs such as community-based reforestation, livelihoods diversification and microcredit program can help the local community's resilience to drought by reducing impacts of drought on social aspects and improving environment condition even with the changing climate.

4. Challenges and Potential

Promoting meaningful participation of stakeholders at various levels of governance is a major challenge in many countries in the lower MRB. In Cambodia, Thailand, and Viet Nam, meaningful community participation is indispensable in various levels of decision making from planning to implementation as well as in monitoring changes in climate and its impacts as drought. An important issue is to ensure the full engagement of the more vulnerable groups, whose lives and livelihoods will be affected by certain adaptation options like relocation, by involving them in exploring alternative response options (Pulhin *et al*., 2010). Based on the current and previous analysis, the following key issues should be considered for better drought risk management in the lower MRB.

Facilitate CCA and DRR Integration at Various Levels. Integration of CCA and DRR concerns at various levels of DRR from national to local should be a major priority for immediate implementation in many countries. An appropriate platform should be established to facilitate the functional integration among the different agencies and sectors concerned with climate change and DRR.

Strengthen the governance system. To strengthen governance and improve the outcomes of integrated drought risk management, enabling policies should be formulated and effective implementation mechanisms developed from the national down the local level in many Asian countries. Such policies and implementation mechanisms should be directed toward mainstreaming of CCA and DRR in all levels of development planning as already pointed out.

Improve information systems and knowledge management. The value of a well informed public to minimize and avoid risks associated with disasters cannot be overemphasized. More reliable and timely information is needed by the public to forewarn them of a forthcoming drought, so they can act more responsively. Equipment, facilities, and trained staff are required to develop a reliable early warning and forecasting system and effectively communicate information to the public in a timely manner.

Apply integrated assessment methods and tools. The application of existing methods and such tools as the sustainable livelihood framework, the SIP approach, and community-based drought risk management methodologies should be encouraged for more robust assessments of climate change impacts, vulnerability, and adaptation including DRR concerns. These tools should be further developed to incorporate future climate change scenarios using downscaled local data.

Ensure natural resources sustainability and resource rights. Countries in the lower MRB are typically dependent on climate-sensitive natural resources for their livelihoods, economic activities, and national income. As mentioned earlier, most of these resources are degraded, making them and the people dependent on them highly vulnerable to damage from drought and climate change.

Build local resilience and reduce vulnerability. The success of integrating drought in the CCA-DRR can be only effectively measured in terms of its local outcomes. Collective efforts by the governments and other stakeholders should therefore be focused on building local resilience of both people and the environment to climatic threats and reduce social vulnerability of communities, particularly the poor.

Advance innovative education and research and development initiatives. Innovative higher education and research and development initiatives that integrate CCA and DRR should be supported and promoted. These should include both formal and non-formal educational systems and go beyond the more conventional classroom-type (or lecture-type) of learning to allow the engagement of the learners in actual field conditions for meaningful learning to take place.

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WATER AND DEVELOPMENT IN THE LOWER MEKONG BASIN

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Abstract

The Mekong is one of the world's great rivers. The Mekong Basin contains the second most biodiverse river in the world after the Amazon, and supports the world's largest freshwater capture fishery of about 2.3 million tons per year. A considerable part of the 60 million people in the lower Mekong Basin (LMB) rely on the goods and services provided by the Mekong River system for their food and livelihood.

Despite impressive economic growth over the past decade within the basin countries, much of the Mekong Basin itself remains among the world's poorest areas. Food security and malnutrition pose great challenges. Half of all households in Cambodia and the Lao People's Democratic Republic have no safe water supply. In a major part of the Mekong Basin, per capita electricity consumption is less than 1% of average electricity consumption in the industrialized world.

Governments realize that developing water resources can stimulate economic growth, reduce poverty, and improve food security. Currently, all LMB countries have poverty reduction strategies and sector plans in place that include water supply for drinking and irrigation, flood management, hydropower generation, fisheries, and other uses of Mekong water. Hydropower is projected to provide an important source of revenue and contribute to the reduction of climate change impacts.

Recent basin-wide assessments by the Basin Development Plan Programme of these strategies and plans on a range of environmental, social, and economic criteria, provided, for the first time, the information the LMB countries need to address each other's concerns and developing a shared understanding of the opportunities and risks of further water resources development. The resulting Integrated Water Resources Management (IWRM)-based Basin Development Strategy, facilitated by the Mekong River Commission (MRC), shows that there is considerable scope for further basin development that can improve water, energy, and food security in the region.

The Strategy also identifies the risks associated with some of these opportunities, including the blockage of migratory fish by dams, which must be managed and mitigated, both at the national level, and where relevant, through cooperation at the transboundary level. The Strategy defines 12 priorities for basin development and basin management in order to move development opportunities to sustainable development.

The Strategy was adopted by the MRC Council in January 2011. Its implementation is now being aligned, to every extent possible, with MRC programmes and national planning and management cycles in order to capture the mutual benefits that can be created by cooperation under the 1995 Mekong Agreement.

1. Introduction

The preparation and adoption in January 2011 of the Integrated Water Resources Management (IWRM) -based Basin Development Strategy by the lower Mekong Basin (LMB) Countries was an important milestone in the history of cooperation under the 1995 Mekong Agreement that established the Mekong River Commission (MRC). The Strategy was prepared at a time when the Basin and the Mekong River itself are seeing significant changes. It has been owned and driven by the LMB countries and facilitated by MRC's Basin Development Plan (BDP) Programme.

This paper aims to inform a wide audience about the implementation of the Strategy. The paper first summarizes the unique characteristics of the Mekong Basin, the peoples' development needs, and government plans. It then outlines the assessment of basin-wide development scenarios that have supported basin-wide discussions on balanced basin development. Finally, the paper highlights the resulting IWRM-based Basin Development Strategy.

2. The River and its Environment

The Mekong is one of the world's great rivers. The Mekong flows for almost 4,800 km from its source in Tibet through the People's Republic of PRC, Myanmar, the Lao People's Democratic Republic (Lao PDR), Thailand, Cambodia, and

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Figure 1: The Mekong River Basin

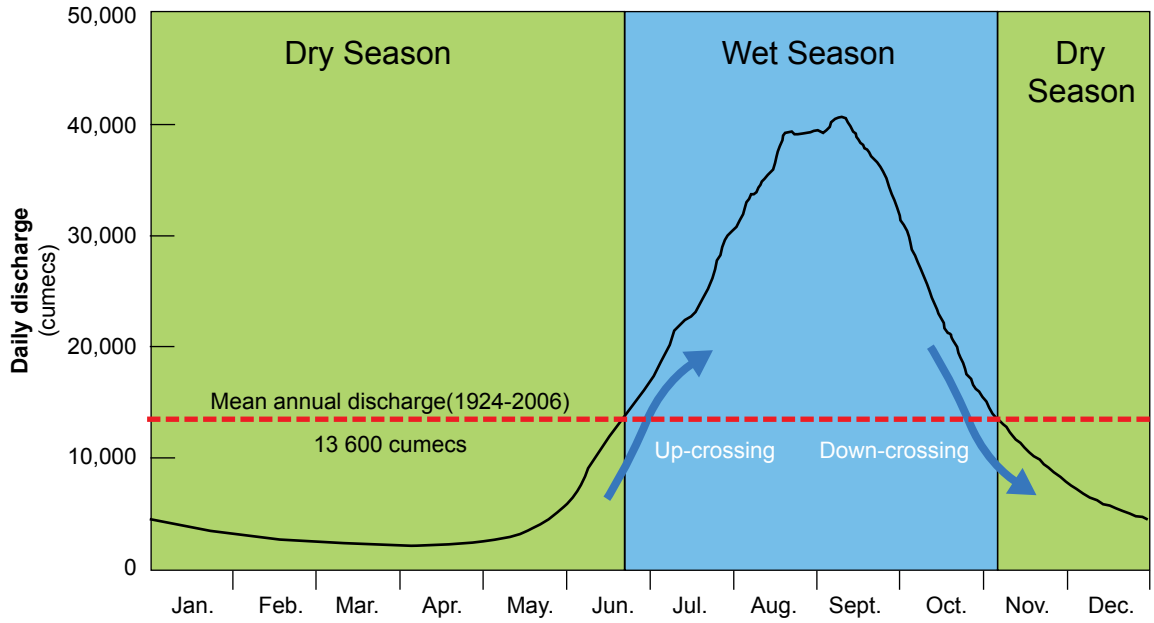
Viet Nam via a delta into the South China Sea, draining a basin area of 795,000 square kilometers (km^2) (the Mekong Basin, Figure 1). The mean annual flow of the Mekong is approximately 475 cubic kilometers (km^3). Per capita water resources amount to 8,500 cubic meters (m^3)/person/year, which is high relative to other international river basins.

The little understood and therefore unpredictable southwest monsoon creates exceptional large seasonal differences in river flows (Figure 2). At Pakse in the southern Lao PDR, mainstem river flows can vary fifty-fold between wet and dry season. The seasonal cycling of water levels at Phnom Penh causes the large "flow reversal" to and from the Great Lake via the Tonle Sap River.

The annual flood pulse and the associated flooding and drying create a rich ecology. The Mekong Basin is the second most biodiverse in the world after the Amazon, and supports the world's largest freshwater capture fishery of about 2.3 million tonnes per year, although, there are reports of declining catches. The outlook for the basin's forests is not positive, with increasing demand for timber and land causing deforestation and soil degradation (MRC, April 2010).

Wet season flooding, although bringing many benefits, can also be very destructive; in contrast drought is common in the dry season, impacting crop production, restricting

Figure 2: Monthly Distribution of Flow in the Mekong Mainstream at Kratie



Cumecs (m^3/s)= cubic meter/second.

navigation, and causing saline water intrusion in the delta. Highly variable rainfall and runoff is 'difficult hydrology' which, without significant investments, often correlates with widespread poverty and restricted economic growth around the world.

3. Socioeconomic Development Needs

Despite impressive economic growth over the past decade in the LMB countries, much of the Mekong Basin itself remains among the world's poorest areas. The total population living in the LMB is about 60 million, with 80% living in rural areas. Many are farmers, who supplement what they grow with the fish they catch and the food and other materials they gather from forests and wetlands. This makes the rich ecology of the basin unique in terms of its contribution to livelihoods, particularly of the poor.

Despite the rich water and related resources, water, energy, and food security and malnutrition pose great challenges. Half of all households in Cambodia and the Lao PDR have no safe water supply and half of all villages are inaccessible by all-weather roads (MRC, April 2010). In a major part of the Mekong Basin, electricity consumption is less than 100 kilowatt hours (kWh) per person per year, which is only 1% of average electricity consumption in the industrialized world. The occasional severe floods claim lives and cause substantial economic losses. Climate change could increase the frequency and intensity of floods and droughts.

Economic growth across the LMB is expected to continue, supported by economic diversification, regional economic integration, and investments in infrastructure and human resource development. Cambodia and the Lao PDR seek to graduate from least developed country status, while Viet Nam seeks middle-income status by 2030 (MRC, March 2011). Increasing populations and living standards and growing economies will accelerate food and electricity demand.

The countries' policies demonstrate that governments recognize that developing the economic potential of the water resources in the Mekong Basin can contribute to increased economic growth, alleviate poverty, and improve food security and malnutrition, as demonstrated in the Viet Nam Delta and Thailand where millions of people have been lifted out of poverty and capture fisheries remain among the highest in the basin (MRC, March 2011).

Currently, all LMB countries have poverty reduction strategies and sector plans in place that include water supply for drinking and irrigation, flood management, hydropower generation, fisheries, and other uses of Mekong water to produce benefits for the many millions who live in poverty, especially in rural areas. Hydropower is projected to provide an important source of foreign exchange earnings and revenues and contribute to the reduction of climate change impacts.

4. Basin Development

Current water resources development in the Mekong Basin is limited relative to most other international river basins. Average annual withdrawals for agricultural and other consumptive uses in the LMB are estimated at 12% of the Mekong's average annual discharge. Diversions from the Mekong mainstream upstream of the delta are so far negligible. Existing storage of water resources behind dams corresponds to 5% of the average annual flow, and does not significantly redistribute water between seasons. As a result, the flow regime in the Mekong mainstream is close to its natural state.

However, this will change during the coming years as a result of accelerated development of water resources, in particular for the generation of hydroelectricity. In the upper Mekong Basin, the PRC is completing its hydropower cascade on the Lancang (Mekong) River. In particular, the Xiaowan dam (currently operational) and the Nuozhadu Dam (to be completed in 2015) with 9.8 and 12.4 billion m3 of active storage, will cause significant seasonal redistribution of flow from the wet season to the dry season, and further reduce sediment transport in the Mekong mainstream (MRC, April 2011).

In the LMB, 26 hydropower projects (>10 megawatts [Mw]) are under construction on tributaries, creating, together with the dams in the PRC, 36 billion m3 of additional active storage. Over the next 20 years, further LMB dams are planned, including 12 mainstream projects and 30 tributary dams, mostly in the Lao PDR. Many tributary dams include significant reservoirs, adding 21 billion m^3 of storage.

There are plans to increase dry season irrigation by 50% (from 1.2 to 1.8 million hectares) in the next 20 years, with the Lao PDR planning to expand irrigation from about 100,000 to over 300,000 hectares. Major irrigation expansion is being studied in Cambodia, linked to investments in flood control in the undeveloped Cambodian delta, and elsewhere linked to hydropower development.

Table 1: indicative Management Arrangements for IWRM

Management Level and Strategy	Purpose of Strategy or Plan	Coordination or Management Body	Partner, Supporting or Implementing Bodies.
Basin Scale: IWRM-based Basin Development Strategy	Guides the water related development and management in the LMB.	MRC	NMCs, national water resources management agencies
National: National water policy and strategy (linked to basin-scale strategy)	Plans the actions to achieve national objectives, follows an IWRM approach.Takes account of the basin scale strategy.	MOWRAM, Cambodia MONRE, Lao PDR MNRE, Thailand MONRE, Viet Nam	NMCs, national planning and sector agencies, private and nongovernment stakeholders
Sub-basin: Sub-basin IWRM Strategy	Plans the actions for local level socio-economic development and resource protection, in accordance with the national IWRM strategy.	RBOs, Province level coordinating mechanism	NMCs, national sector agencies (province level)
Watershed: Watershed Plan of Action	Provides information into sub-basin level plans	Watershed Committees	Districts and commune agencies, local communities.

MNRE = Ministry of Natural Resources and Environment, MONRE = Ministry of Natural Resources and Environment , MOWRAM = Ministry of Water Resources and Meteorology, NMC = National Mekong Committee, RBO = River Basin Organization .

Mainstream water transfers have long been considered by Thailand, to complement national approaches to alleviate droughts in the northeast (MRC, March 2011).

LMB countries also plan to further develop aquaculture and improve fisheries management, navigation, flood and drought management, and tourism development. Aquaculture growth is forecast to double to 4 million tonnes/year in the next 20 years, so that total basin-wide fish yield (capture and aquaculture) is likely to increase, despite development impacts (MRC, April 2011).

In many of these areas, investment from the private sector now outweighs public sector investments. When private sector projects begin to dominate, the government will require strong government regulatory systems and enforcement capacity, and the readiness to interpret national policies to include emerging good practice. This means a more strategic set of skills and capacities for the central regulating and resource management agencies, (see Table 1) and stronger supporting laws and regulations.

5. Water Resources Management

Water resources management in the LMB is a mix of a "cooperative and coordinating model" at the basin scale (facilitated through the MRC) and four national models, where individual sovereignty, customs, and administrative systems dominate. MRC, through the 1995 Mekong Agreement, acts as a focal point for the cooperation, and assists the member countries in achieving their basin-scale aims through provision of shared information, technical guidance, and mediation.

Since 1995, the MRC has made slow but sure progress, with member country agreement to a procedural framework for cooperation and the development of a regionally recognized knowledge base. It also established a participatory process for basin planning and commenced an effective dialogue with the PRC and Myanmar. Most of MRC's activities are now implemented through sector or thematic programmes. In 2009, core functions were defined. Some of the core function activities will be gradually decentralized to the member countries.

Each country is implementing IWRM in a way that suits its particular circumstances. There have been large changes in all countries, particularly relating to developing clear statements of national water-related policy and Strategy. An improving institutional and regulatory framework increasingly supports these policies, and removes uncertainty as to which agency has the role of the "water resources manager" (Table 1).

All countries are strengthening participatory approaches to river basin and sub-basin planning and management. Thailand has a well structured framework for River Basin Organizations (RBOs) covering all major sub-basins in the country, while the Lao PDR Viet Nam and are now commencing an RBO approach in critical river basins.[4] New decentralization policies that will enable water related decisions to be taken at the provincial levels.

[4] Critical sub-basins need a more holistic and integrated approach in water resources planning, development and management. In such basins, RBOs or provincial departments of the national water and environment agencies (MNRE, MONRE, MOWRAM, MONRE) would need to play their most prominent role in engaging stakeholders and steering and coordinating the planning and implementing activities of Sector agencies (agriculture, hydropower, etc.) and Provinces.

All countries are supporting capacity building programmes for IWRM and introducing new technical, modelling and analytical tools and approaches to support water planning and management. Environmental protection objectives are prominent in the National Socio-economic Development Strategies of all countries. Approaches to stakeholder participation and consultation are being strengthened, building on each country's systems, approaches and cultures relating to community or mass participation.

6. Balancing Development and Protection

The LMB countries' ambitious development plans will bring with them both synergies between water resources developments, and trade-offs, where benefits in one area or activity create detriments for another. For example there can be synergies between hydropower, irrigation, and upland watershed management, with some benefits occurring for all. Trade-offs at the transboundary level will largely be about hydropower benefits, on the one hand, and the losses caused by the blockage of fish migration routes and other potential impacts resulting from this infrastructure.

Trade-offs in particular require much analytical work and negotiation between countries, or between sectors, to find the middle ground (or balancing point) where all key players and stakeholders are prepared to agree. All of this requires strong IWRM understanding and capabilities across the basin, and across institutions, and time for consultation and to develop preferred negotiating positions. It will also require close consideration of a range of complementary measures that may be needed to offset or mitigate the impacts of new development proposals.

The BDP Programme has studied the potential transboundary synergies and trade-offs through a cumulative impact assessment of basin-wide development scenarios (MRC, April 2011), with engagement of many stakeholders across the Mekong Basin (see the last Section). The process was technically guided and supervised by the Regional Technical Working Group (RTWG), comprising technical experts drawn from the line agencies, research institutions, national Mekong committees (NMCs), and the MRC Programmes. Other studies have contributed to the scenario assessment, such as the strategic environmental assessment (SEA) of hydropower on the Mekong mainstream (ICEM, October 2010).

7. Scenario Assessment

Each scenario was formulated to represent different combinations of nationally planned sector development, with a focus on public and industrial water supply, irrigation, hydropower, and flood protection. These are the sectors identified by the LMB countries as having the greatest risk of transboundary environment and social impacts. The LMB countries agreed to assess the scenarios against 42 economic, environmental, and social criteria that provide a picture of how well each scenario meets the socioeconomic development and environment protection objectives of each country, as well as the basin's shared goals. In addition, a basin-wide equity criterion is included that measures the degree of equitable development between each country that each scenario produces.

The scenarios selected by LMB country scenarios fall into four main categories: baseline situation (year 2000), definite future situation (2015), foreseeable future situation (2030), and long-term future situation (2060). The scenarios for the foreseeable future and longer-term future were assessed with and without the potential modifying influence of climate change.

Hydrological changes caused by each scenario have been assessed with MRC's suite of simulation models, taking into account the developments and plans in the upper Mekong Basin. Based on the hydrological changes and physical impacts caused by each scenario, a multidisciplinary expert group had conducted an integrated assessment with the set of agreed criteria. The group was assembled from MRC staff and riparian and international scientists and consultants.

The scenario assessment results are reported in a main report and 13 technical reports (MRC, April 2011). Some assessment results are presented in Table 2 and Figure 3 below. Table 2 shows that both benefits and negative impacts of the considered scenarios are spread unevenly across the four countries, which highlights the need for transboundary cooperation to reach mutually acceptable decisions. Figure 3 shows that the lower of the proposed 11 mainstream dams have the largest impact on LMB's capture fisheries and environmental values. The losses are particularly severe in Cambodia and Viet Nam.

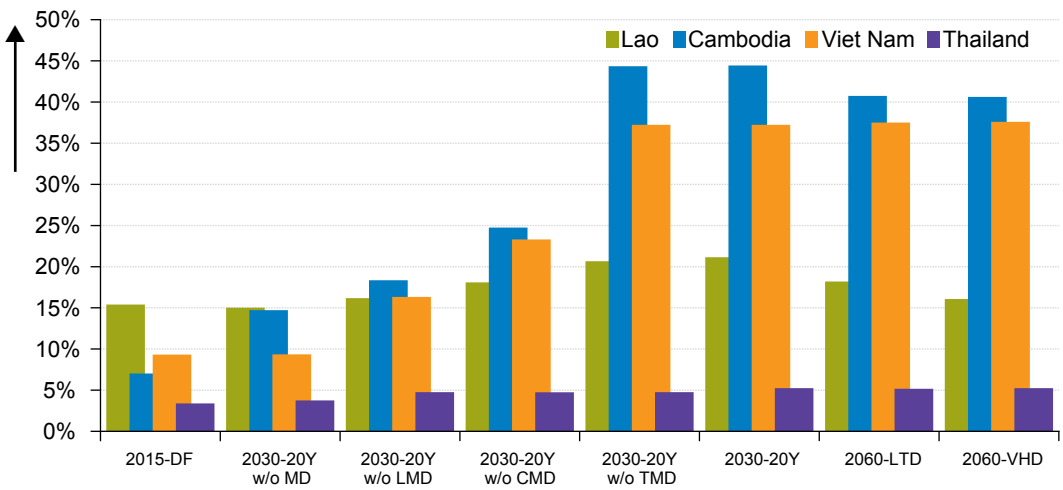
The assessments of climate change point clearly toward more variable conditions within the basin and increasing runoff in the longer term. In the foreseeable future (next 20 years), climate change could further increase the already

Table 2: Comparison of Economic Net Present Value in Each Scenario with the Baseline by Sector and Country

($ million)

	Definite Future	20-Year Plan w/o MS Dams	20-Year Plan w/o Lower MS Dams	20-Year Plan w/o Thai MS Dams	20-Year Plan w/o Cambodia MS Dams	20-Year Plan	20-Year Plan + Climate Change	Long Term Dev't Scenario	Long Term Dev't + Climate Change	Long Term Very High Dev't
Hydropower	11,491	17,603	25,002	28,706	30,333	32,823	32,823	37,865	37,865	38,787
Irrigated Agriculture	0	1,659	1,659	1,659	1,659	1,659	1,659	4,268	4,268	16,129
Reservoir Fisheries	91	107	132	202	169	215	215	420	420	473
Aquaculture	1,129	1,261	1,261	1,261	1,261	1,261	1,261	1,892	1,892	2,522
Capture Fisheries Losses	-946	-732	-952	-1,914	-1,218	-1,936	-1,936	-1,818	-1,818	-1,801
Wetland Area Reduction	-228	-176	-178	-225	-178	-225	101	-260	36	-310
Eco-hotspots/Biodiversity	-85	-220	-240	-330	-305	-330	-415	-435	-525	-700
Forests	-153	-183	-228	-349	-254	-372	-372	-731	-731	-822
Recession Rice	-144	-173	-175	-178	-176	-178	278	-226	185	-274
Flood Mitigation	461	360	360	360	360	377	-273	408	-296	432
Saline Area Reduction	20	25	23	21	23	27	-2	22	-2	16
Riverbank Erosion	0	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Navigation	64	64	64	64	64	64	64	64	64	64
Total LMB	**11,700**	**19,596**	**26,729**	**29,277**	**31,739**	**33,386**	**33,404**	**41,469**	**41,359**	**54,516**
Lao PDR	6,595	11,688	17,636	18,927	22,632	22,588	22,604	26,401	26,501	29,608
Thailand	1,095	2,750	3,913	3,970	4,223	4,410	4,445	5,011	5,097	6,351
Cambodia	693	1,446	1,351	2,237	1,143	2,237	2,628	5,302	5,470	13,134
Viet Nam	3,317	3,711	3,828	4,142	3,741	4,151	3,727	4,755	4,292	5,423
Total LMB	**11,700**	**19,596**	**26,729**	**29,277**	**31,739**	**33,386**	**33,404**	**41,469**	**41,359**	**54,516**

Figure 3: Capture Fisheries Losses Relative To Baseline (%)



Notes: 2015-DF (Definite Future Scenario), Baseline plus PRC dam cascade and 26 additional hydropower dams in LMB.

2030-20Y (LMB 20-Year Plan Scenario), 2015 DF plus 11 LMB mainstream dams and planned tributary dams (30), irrigation, and water supply.

2030-20Y-w/o MD (LMB 20-Year Plan Scenario without LMB mainstream dams), as above, excluding 11 LMB mainstream dams.

2030-20Y-w/o LMD (LMB 20-Year Plan Scenario without lower mainstream dams), as above, plus 6 LMB mainstream dams in Northern Lao PDR.

2030-20y-w/o CMD (LMB 20-Year Plan Scenario, excluding the two Cambodian mainstream dams).

2030-20Y-w/o TMD (LMB 20-Year Plan Scenario, excluding the two Thai mainstream dams).

2060-LTD LMB (Long-term Development Scenario), 2030-20Y plus further infrastructure developments in LMB.

2060–VHD LMB (Very High Development Scenario), as 2060-LTD, extended to full potential infrastructure developments.

high year-to-year variability of wet and dry season flows, as well as the frequency and intensity of floods and droughts, reversing the reduction of flooding (and wetlands) caused by current developments in the Decision Support System (DSF). In the longer term, the increased average flood season flows could be offset to some extent by the increased tributary storage.

Scenario data have been extensively reviewed and verified by each country. In all of the above cases, the data appear adequate to support basin-scale assessments. The risks of some incomplete data and knowledge were recognized. However, accelerated developments have demanded early information on transboundary impacts. During the process, the highest priority areas where greater understanding is needed have been identified. These knowledge gaps will be addressed during the implementation of the IWRM-based Basin Development Strategy.

8. The IWRM-based Basin Development Strategy

The Strategy has been owned and driven by the LMB countries through a process of scenario assessment and has been informed by wide stakeholder engagement across the basin. For the first time, the countries have reached—through information sharing and consultation—on a common understanding of each other's plans for water resources development, drawing initial conclusions together on likely transboundary impacts, addressing each other's concerns, developing a shared understanding of the opportunities and risks of water resources development, and agreeing on 12 strategic priorities to guide future decisions on basin development and management (MRC, March 2011).

The Strategy recognizes data and knowledge limitations. It therefore defines a dynamic basin development planning process that will be reviewed and updated every 5 years to ensure that decision making on water and related resources is based on up-to-date knowledge and feedback. A first update of the Strategy is expected in 2015.

8.1 Development Opportunities

The Strategy removes some longstanding barriers to realizing opportunities for sustainable development of the Mekong River. It shows that there is considerable scope for further basin development that will improve water, energy, and food security in the region. This makes the Mekong Basin unusual, if not unique among the world's river basins where water demand often outstrips supply.

The completion of two large storage dams on the Lancang (Mekong) in the PRC and continued dam construction on LMB tributaries for hydropower generation will considerably increase the dry season flows by redistributing water from the wet to the dry season. The increased flows offer an opportunity to source the countries' ambitious irrigation plans—including possible diversions into the Cambodian delta and into northeastern Thailand—without affecting the natural dry season flows, which will be protected through the MRC Procedure on the Maintenance of the Flows on the Mainstream (PMFM).

There is considerable potential for further development of tributary hydropower in the LMB, especially in Cambodia and the Lao PDR, requiring a focus on sustainability both at project and transboundary levels. There is an opportunity to consider some mainstream hydropower, provided the uncertainties and risks associated with mainstream dams are fully addressed, and the opportunity is provided for member countries to consider and address jointly the transboundary impacts of any proposed project (through the MRC Procedure on Notification, Prior Consultation and Agreement [PNPCA]).

There is considerable potential for other water-related developments, such as fisheries, navigation, flood and drought management, tourism, and environment and ecosystem management. The Strategy prioritizes the preparation of basin-wide strategies and the further identification of alternative opportunities beyond the water sector.

However, the Strategy also identifies the significant risks associated with some of these opportunities, including the trapping of sediments and blockage of migratory fish by dams. These risks must be managed and mitigated, both at the national level, and where relevant, through cooperation at the transboundary level.

8.2 Strategic Priorities

The Strategy defines a process to move from development opportunities to implementation and sustainable development, including the following strategic priorities for basin development:

- Opportunities and risks of current developments (to 2015) addressed, including coordination between LMB countries and cooperation with the PRC achieved, to ensure increased dry season river flows; the PMFM implemented to protect the maintenance of the flow on the mainstream; and

risks of committed projects managed
- Irrigated agriculture for food security and poverty alleviation expanded and intensified; guidelines for fish-friendly development of irrigation schemes and for promoting integrated pest management prepared
- Environmental and social sustainability of hydropower development greatly enhanced, and sub-basins with high ecological value protected
- Essential knowledge acquired to address uncertainty and minimize risks of identified development opportunities, including knowledge on migration and adaptation of fish; trapping and transport of sediments and nutrients; changes in biodiversity, and social and livelihood impacts; climate change trends and extreme events; long-term flood management options for the Mekong delta; and alternative power options, including innovative hydropower schemes that do not affect connectivity in the lower basin
- Options for sharing development benefits and risks in the Mekong Basin identified, based on review of international approaches and case studies
- Climate change adaptation strategy prepared and its implementation initiated; pilot projects relevant to water-related sectors completed and scaling-up initiated
- Basin planning considerations integrated into national planning and regulatory systems, including the implementation of MRC procedures and guidelines, and the maintenance of a register of existing, ongoing, and planned water-related projects.

The Strategy defines strategic priorities for basin management, an essential companion to basin development to ensure sustainability and allow a more holistic and integrated approach to future updates of the development scenarios and this strategy, as follows:

- Basin objectives and management strategies defined for water-related sectors, including fisheries, flood and drought management, wetland management, and navigation
- National basic water resources management processes strengthened, including water resources monitoring, water use licensing, compliance assurance of license conditions and regulations, and data and information management
- Basin-level water resources and related management processes strengthened, including the implementation of MRC procedures, state-of-basin monitoring and reporting, project cycle monitoring, enhanced stakeholder participation, and developing networks of national water resources management agencies and of RBOs
- Rigorous basin-wide environmental and social objectives and baseline indicators defined to provide a stronger framework for basin and national planning, including the assessment of development scenarios and the implementation of MRC procedures
- Water resources management capacity-building programme implemented, linked to MRC's overall initiatives, and complementary to national capacity-building activities.

The Strategy identifies a long list of essential basin-wide water resources management guidelines and sector guidelines needed for addressing basin-wide issues in sector development and management. Some of the guidelines have been or are being prepared, such as the transboundary environmental impacts assessment framework, preliminary design guidance for mainstream hydropower, and guidelines for integrated flood risk management.

8.3. Implementation of the Strategy

The IWRM-based Basin Development Strategy includes a road map setting out priority actions, timeframes, and outcomes of Strategy implementation. An early action is the preparation in 2011 of a Basin Action Plan that effectively addresses the development opportunities and strategic priorities in the Strategy by the LMB countries (NMCs, line agencies, and RBOs) together with the MRC progammes. The implementation of the Strategy will be supported by the BDP Programme (MRC, July 2011).

The Basin Action Plan comprises a coherent and consistent set of one regional action plan and four national indicative plans, one per LMB country. The regional action plan will include those activities that require joint implementation between two or more countries and which are best undertaken at a regional level. The national indicative plan will take account of existing national policies, regulations, and plans and will identify and describe the activities (both ongoing and supplementary) that the country believes best address the basin-wide development opportunities and strategic priorities in the agreed IWRM-based Basin Development Strategy (MRC, May 2011).

Table 3: Summary List of Main Consultations

Event	No. of meetings	Participants	Objective
MRC Joint Committee meetings	8 at the regional level	20-40	Review and approval of scenario formulation and assessment
National advisors/facilitators	12 at the regional level	5	Advisory, facilitation and mediation services
Regional BDP stakeholder forums	Annually at the regional level	150-300	Discussion of national positions at the regional level
Regional Technical Working Group	9 at the regional level	40-60	Technical validation of assessments
National consultations	4-7 in each country	20-40	Development of national policy and negotiation positions
JC Working Group Meeting	5	15-20	Negotiation of Strategy
Sub-area forums	2 in priority sub-areas	50-100	Data and information improvement
Transboundary meetings	1 in the 3Ss basin	120	Discussion of scenarios and improvement of transboundary cooperation
Meetings with interest groups (M-POWER, private developers, etc.)	6	10-100	Discussion of assessment approaches, methodologies, tools, data, results etc.

Most activities in the Basin Action Plan are likely to be nonstructural projects[5] and enabling activities.[6] It is probable that countries will choose to keep the identification and preparation of national infrastructure projects outside the national indicative plan, as they are clearly within national remit, and only enter MRC monitoring and reporting processes when countries are ready to submit proposed projects for the PNPCA process. Whatever the countries decide, it is important that the implementation of the Strategy promotes confidence and trust in the PNPCA process and facilitates the early referral of possible projects, and the use of MRC expertise in the early consideration of new projects.

Each activity identified in the Basin Action Plan will have an 'activity information sheet' sheet completed, which includes fields for objectives, scope, deliverables, monitoring indicators, implementation responsibilities, etc. The implementation of these activities will be aligned, to every extent possible, with MRC programmes and national sector planning and management cycles. Several regional activities have been taken up already by MRC programmes, supported by existing and new donors.

The completed activity information sheets will be used to promote unfunded regional and national activities and to monitor the implementation of the Strategy. The monitoring system will measure implementation progress and the achievement of the outcomes of the Strategy. It is proposed that this will be an electronic system and that consideration is given to web-based entry of progress information and access to progress reports.

It is expected that the implementation of the Strategy will lead to the following benefits for the Mekong Basin and the countries:

- Capture the mutual benefits that can be created by cooperation under the 1995 Mekong Agreement.
- Move the MRC beyond cooperation primarily on knowledge acquisition toward cooperation on water development and management.
- Lead to a strengthened framework for basin planning and management, including the improved implementation of MRC procedures and guidelines.
- Lay the foundation to a strengthened and broader-based approach to the formulation and assessment of scenarios and the updating of the Strategy in 2014/2015.
- Highlight areas where additional funding support is needed.

9. Stakeholders and Participatory Process

The scenario assessment and the IWRM-based Basin Development Strategy is the outcome of a three-year consultation process in which, primarily, each of the four

[5] Examples are investments in improved management of water and related resources, such as monitoring, flood management, navigation, fisheries, and environmental health.

[6] Examples at the regional level are: studies to reduce knowledge gaps, preparation of best practice guidelines, and strengthening cooperation with the PRC; at the national level: the institutionalization of MRC procedures within national systems, improvements of national plans and regulations, preparation of sector and/or sub-area strategies (fish, navigation, etc.), improvement of stakeholder participation, strategic directions to benefit from the development opportunities and to prevent or mitigate the negative impacts of hydropower development, and capacity building using guidelines and tools prepared at the regional level.

member States has been fully engaged and steering the planning process through collective decision taking at every stage. A summary of the main consultations held with national agencies, provinces, RBOs, community representatives, NGOs, academia, development partners, dialogue partners and others is provided in Table 3, illustrating the commitment made to ensure relevance and quality of the scenarios and Strategy.

To ensure transparency, all relevant documents have been posted on the MRC web site. The Strategy preparation, including scenario assessment, was overseen by experts from relevant national line agencies, national advisors and the MRC. An independent Panel of Experts provided an expert review of the underlying assessments and drafts of the Strategy.

The wide stakeholder engagement will continue during the implementation of the IWRM-based Basin Development Strategy. This will include national stakeholder forums and regional MRC forums with a mandate to undertake regular stakeholder reviews of the implementation of the Strategy.

10. Conclusion

For the first time since the signing of the 1995 Mekong Agreement, the four lower Mekong Basin countries have negotiated a Basin Development Strategy that provides opportunities for further development of the Basin's water resources and defines strategic priorities to move opportunities toward sustainable development and improve the management of water-related resources in the Mekong Basin. The Strategy recognizes data and knowledge limitations; however, accelerated development pressures demand guidance. The Strategy is a dynamic framework that will be reviewed and updated every 5 years to ensure that decision making on water and related resources is based on updated knowledge of the basin. The next update is expected by 2015.

At the heart of the Strategy is the move beyond regional cooperation primarily on knowledge acquisition towards cooperation on water development and management, and the move beyond national, sectoral planning toward comprehensive basin planning. The implementation of the Strategy has been initiated with the coordinated preparation of action plans at the regional and national levels. The implementation of the identified activities will be aligned, to the extent possible, with MRC programs and national sector planning and management cycles. The next few years will show how the countries, together with the MRC Programmes, will capture the mutual benefits that can be created under the Strategy.

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MAINSTREAMING OF WETLAND ECOSYSTEM SERVICES IN POLICY PLANNING PROCESS – CASE OF VIET NAM

Kim Thi Thuy Ngoc[1]

Abstract

There is a great diversity of wetlands in Viet Nam that possess a range of resources, biodiversity, functions and important social, economic and cultural values. With an area of more than 10 million hectares, wetlands can be found in almost all ecological regions of the country. These wetlands play a vital role in the lives of the local people and the socio-economic development of the country. However, over the last fifteen years, wetland in Viet Nam has reduced both quantity and quality. The natural area of wetlands has been reduced while artificial wetlands have increased.

Environmental services of wetlands in Viet Nam include groundwater recharge and discharge, freshwater supply, climate regulation, biomass export, flood protection, wave and storm prevention, shoreline erosion control, coastline stabilization, and maintenance of biodiversity. Value of wetland is very significant. Understanding those environmental services would be initial input for mainstreaming the services in policy planning process to sustainable use and conservation of wetland.

The paper will review environmental services of wetland in Viet Nam, analyze the tools and methodologies applied for mainstreaming environmental services in policy planning and propose the approach to mainstream environmental services of wetland in planning progress.

1. Wetlands in Viet Nam

Wetlands in Viet Nam comprise of two groups: inland wetlands and coastal wetlands. Inland wetlands are present in all ecological regions and are very diverse in terms of type, morphology, resources, functions, values and potential for exploitation, usage and protection. Inland wetlands include permanently flooded river deltas, creeks, permanent or temporary rivers and streams, freshwater lakes, peatland, swamps, saltwater lakes, mountain wetlands, geothermal wetlands, aquaculture ponds, lakes with areas greater than eight million hectares (ha), and marshes. Coastal wetlands are distributed widely along the coastline of Viet Nam, and include estuaries, tidal flats, lagoons, and marine water bodies with a depth not exceeding six meters at low tide.

Mangrove forests and mudflats are concentrated mainly in deltas, estuaries and tidal areas. Lagoons are present mainly along the coastline of central Viet Nam, from Hue to Ninh Thuan. Coral reefs and seagrass beds are distributed in the coastal area of south-central Viet Nam.

The area of wetlands in Viet Nam has decreased dramatically over recent decades. According to Mai Trong Nhuan[2], tidal wetlands in estuarine areas of the Mekong Delta decreased in area from 1,473,889 ha in

Figure 1: Decline of Mangrove Forests, Viet Nam, 1990-2007

[1] Head, International Cooperation Division Institute of Strategy and Policy on Natural resources and Environment (ISPONRE), Ministry of Natural Resources and Environment (MONRE). Viet Nam.

[2] As Mai Trong Nhuan, Inventory, Assessment and Planning of significant international and national wetland.

Box 1: Loss of mangroves in Viet Nam[3]

In 1943, the mangrove area was preliminarily estimated at 408,500 ha (Maurand, 1943), reducing to about 290,000 ha in 1962 (Rollet, 1963), to 286,400 ha after mangroves were sprayed with herbicides (1975) and to 252,400 ha in 1982 (Hong and San 1993). In Northern Viet Nam, from Mong Cai to Do Son, during 1964 – 1997, mangrove area reduced by 17,094 ha. The Red river plain saw mangrove reduction of 4,640 ha from 1975 to 1991, and only after two years (1993) a decrease of 7,430 ha (National Environment Agency, 2003).

The coastal zone of Southern Viet Nam witnessed little change of mangroves (from 250,000 ha to 210,000 ha) during 1950 – 1960; yet, the figure reduced to 92,000 ha of mangroves in 1975 due to the spraying of warring herbicides by the American force (1962 – 1972). During 1973 – 1988, annually, about 6,600 ha of mangroves were lost on average. In Minh Hai province alone (now are Ca Mau and Bac Lieu provinces), from 1983 to 1988, each year saw the loss of 6,820 ha, especially in 1988 – 1989 as much as 10,000 ha were lost (Institute for Fisheries Planning, 2003; Institute for Forest Inventory and Planning, 2003). During 1990 – 1995, 3,200 ha of mangroves were lost annually; in 1990 – 1991 alone, nearly 9,000 ha of mangroves were lost.

Source: Le Nguyen Hong, 2009.

1995 to 1,409,289 ha in 1999. The area of Bach Dang Estuary decreased from 64,169 ha in 1934 to 30,729 ha in 1997. Natural mangrove forests are being converted into aquacultural ponds, tourism facilities and planted forests. Over the past twenty years, 183,724 ha of mangrove forests have been lost while aquacultural areas have increased to 1.1 million ha in 2003. Data reported by the Southern Institute of Water Resources have shown that more than 50% of the total area of the Mekong Delta (approximately two million ha) is currently affected by salinisation. One of the reasons for this phenomenon is the loss of mangrove forests along the coast. Peatlands in U Minh covered about 90,000 ha in 1990, but as of 2005 only about 12,000 ha were left (Southern Sub-FIPI, 2005).

2. Ecosystem Services of Wetlands in Viet Nam

Functions of wetlands in Viet Nam include groundwater recharge and discharge, freshwater supply, climate regulation, biomass export, flood protection, wave and storm prevention, shoreline erosion control, coastline stabilization, and maintenance of biodiversity. Wetlands also provide opportunities for recreation, tourism and a favorable environment for many economic sectors including fisheries, forestry, water transportation, energy production, tourism, and mineral exploitation. Wetlands are vital sources for a major part of Viet Nam's population since they provide many benefits and contribute immeasurable social, economic, cultural and environmental values to the industrialization and modernization in Viet Nam.[4]

Recharge and discharge of groundwater: During the rainy season, when there is a surplus of surface waters, wetlands act as storage tanks that allow water to gradually infiltrate into the groundwater systems later during the dry season. This is a continuous process that supplies water for groundwater aquifers. In addition, a continuous process of recharge and discharge of groundwater from wetlands and aquifers also contributes to groundwater purification. For instance, wetlands of Melaleuca forests in U Minh Thuong play a role in water storage, humidity regulation and moisture maintenance of the peaty soil layer. They can also prevent soil acidification and act as sources of water for domestic uses.

Trapping of sediment and toxic substances: Wetland ecosystems (especially lakes, mangroves, tidal marshes, and coastal bays) can function as sinks trapping sediments, pollutants, toxic substances or general wastes, in order to purify water and reduce the possibility of marine water pollution.

Nutrient retention: Wetland ecosystems can absorb nutrients, mainly nitrogen, phosphorus and micro minerals, which are important for micro-organisms, fisheries and forestry development. This process also reduces eutrophication in the Red River and Mekong River floodplains and some other waterbodies.

[3] Le Nguyen Hong, Mangrove Forest In Viet Nam:Management and Proposed Action Plans for Preservation and Development.

[4] Overview of Wetlands Status in Viet Nam Following 15 Years of Ramsar Convention Implementation.

Microclimate regulation: This function is particularly evident in areas having seagrasses, mangroves, and coral reefs, where wetlands contribute to balancing O_2 and CO_2 concentrations in the atmosphere, regulating microclimate (temperature, humidity, precipitation) and reducing the greenhouse effect.

Flood control: Wetlands (particularly mangroves, natural and man-made lakes) can function as water storage tanks, regulating rainfall and surface runoff, which slows the flow of flood water and reduces floods in surrounding areas of reservoirs such as Hoa Binh, Thac Ba, and Tri An.

Biomass production: Biomass produced in wetlands provides food sources for aquatic organisms, livestock, wildlife and domestic animals. In addition, part of the nutrient source from rotten and decomposed organisms is transported by surface flows and provides food sources to downstream and coastal areas.

Maintenance of biodiversity: Many wetlands, especially mangroves, coral reefs, and seagrasses, are favourable breeding, nursing and growing areas for a variety of wild fauna and flora. Many genetic resources, particularly those of rare and valuable species, are preserved in wetlands.

Wave and storm protection, shoreline stabilisation and coastline erosion control: Thanks to vegetation cover, especially mangrove forests, seagrass beds, and coral reefs, coastal wetlands can protect shorelines from waves, tides, erosion and tsunamis. They also provide a favourable environment for alluvial deposition which contributes to the stabilisation and extension of alluvial flats. Extensive coral reefs have reduced the intensity of waves that otherwise could affect coastlines and the areas surrounding islands during hurricanes and tsunamis. Recently, many natural wetlands (mangroves, coral reefs, seagrass beds) have been considerably degraded due to over-exploitation and land reclamation activities for agricultural and aquacultural development. Thus, shorelines are undergoing continuous change and coastline erosion has increased, especially along the coast of the Red River Delta, central and south-central Viet Nam, and the Mekong Delta.

Other functions of wetlands: Apart from the functions mentioned above, wetlands play a vital role in providing a favourable environment for economic activities in many sectors including agriculture, fisheries, forestry, water transportation, tourism, and mineral exploitation. Notably, 80% of Viet Nam's population is settled within wetlands.

Table 1: Type of Ecosystem Services of Wetlands in Viet Nam

Services	Value
Provision Services	
Food	Total value of mussel exploitation in National Park Xuan Thuy in 2004 has the estimated value of 7 to 10 million USD, contributing to local community income (Nguyen Huu Ninh, Mai Trong Nhuan, *et al.*, 2003).
Fresh Water	The wetlands in high areas such as Bien Ho, Ayun ha (Gia Lai province), Da Teh (Lam Dong province) has significant role in providing water sources for daily activities of local community and cattle.
Regulation Services	
Flood control	Wetlands (particularly mangroves, natural and man-made lakes) can function as water storage tanks, regulating rainfall and surface runoff, which slows the flow of flood water and reduces floods in surrounding areas of reservoirs such as Hoa Binh, Thac Ba, and Tri An.
Trapping of sediment and toxic substances	Wetland ecosystems (especially lakes, mangroves, tidal marshes, coastal bays and mangrove such as Xuan Thuy naitonal Park, Van Uc mouth lake, Can Gio Mangrove, Tam Giang – Cau Hai – Thi Nai lagoon) can function as sinks trapping sediments, pollutants, toxic substances or general wastes, in order to purify water and reduce the possibility of marine water pollution.
Microclimate regulation	Study results of Le Van Khoi *et al.* (1999) display that on an area of 20,000 ha of mangrove plantations in Can Gio over the past 25 years, the forest trees have absorbed 10,164,440 tons of CO_2 and the amount of O_2 produced has been 6,776,296 tons.
Recharge and discharge of groundwater	Melaleuca forest (U Minh Thuong) plays role of water reservation, moinsure control and keep the peatland level in wet conditon.
Cultural services	Tourism wetlan areas such as Ha Long Bay, Cat Ba Island, Con Dao Island, the beautiful beaches in Phan Thiet and Vung Tau, Phuong Nha-Ke Bang Cave, the historical monument in U Minh Thuong National Park, and ecotourism areas of Xuan Thuy Wetland Nature Reserve and Ba Be National Park have attracted many international and domestic tourists.

Ecosystem services of wetland play important roles for human well-being. The wetlands in the Mekong Delta encompass areas of valuable biodiversity and fertile areas for cultivation. It is these areas in the Mekong Delta that have been since long the rice granary of Viet Nam, which contribute around 80% of the exported rice quantity of the nation.

Mangrove forest plays an important role in disaster control. Estimated value of 3,100 ha of mangrove in Xuan Thuy National Park, Nam Dinh province would be around 2.6 milion VND for its protection function for 10.5 km of dyke system in the area. In average, the value of mangrove forest for dyke protection can be calculated as 853,000 VND/ha/year.

3. Policy Framework for Wetland Management in Viet Nam

Over the last fifteen years, the Government of Viet Nam has paid great attention to the formulation and completion of a legislation system to establish a legal foundation for national governance, creating favourable conditions for international integration. A number of these regulations are related to wetland management. Legislation on environmental protection and nature conservation has contributed significantly to wetland protection. Viet Nam has passed more than 500 regulations on environmental protection and nature conservation since 1976. However, of these, only about ten refer directly to wetlands, while the rest are indirectly related through the protection of various components of wetlands such as water resources and wildlife protection.

Table 2: The Cuu Long River Delta Ecosystem Provisioning Services[5]

Item	Unit	1990	1995	2001
1. Food output by paddy	10^6 ton	7.5470	13.986	16.1720
– Paddy	10^6 ton	7.5230	13.885	16.0720
– Corn	10^6 ton	0.0232	0.100	0.0938
2. Buffalo	indvdl.	154,056.0000	124,588.000	63,538.0000
3. Cow	indvdl.	186,017.0000	149,872.000	197,210.0000
4. Pig	10^6 indvdl.	1.1180	2.408	2.9780
5. Poultry	10^6 indvdl.	18.1740	34.052	44.2120
6. Expltd. Timber output	m^3	49,652.0000	315,631.000	459,262.0000
7. Expltd. Fuelwood output	10^6 ster	0.5120	2.163	3.6960
8. Caught sea product output	ton	126,398.0000	421,286.000	648,121.0000
9. Caught aqu. product output	ton	12,860.0000	132,610.000	218,486.0000
10.Brding aqu. product output	ton	20,884.0000	261,797.000	414,386.0000
11.Export turnover	10^6 USD	338.3960	730.485	1,468,946.0000

Table 3: Maintenance and Repair Cost of 20.7 km of Dyke without Protection Mangrove Forest in Giao Thuy (1997 – 2006) (Price in 2006, discount rate r = 10%)[6]

Year	Cost (VND)	Average cost (VND/km)
1997	1,469,403,442	70,985,674
1998	1,540,766,1707	74,433,174
1999	5,846,408,026	282,435,170
2001	1,174,909,885	56,758,932
2002	1,397,300,701	67,502,449
2003	2,376,497,838	114,806,659
2004	1,719,652,000	83,074,976
2005	30,734,000,000	1,484,734,300
2006	615,560,000	29,737,198
Total	**46,874,498,598**	
Average	**5,208,277,622**	**251,607,615**

[5] Mekong Delta River Wetland Ecosystem Assessment.

[6] Nguyen Tan Phuong, Forest valuation in Viet Nam.

Viet Nam has formulated and organised the implementation of an action plan relating to the conservation and development of wetlands. Some key documents of relevance to wetland management are the following:

Management strategy to the year 2010 for a protected area (PA) system in Viet Nam, with its main goals to establish and manage effectively PAs located in various ecosystems and to contribute to the protection of natural resources, biodiversity, while preserving the bountiful and unique landscape of Viet Nam. Various activities to develop and manage PAs are provided through this strategy. Conservation activities should be combined closely with development strategies, in order to promote roles and functions of a PAs system. The decisive principle of the strategy is sustainable development. The Strategy forms the basis for developing plans to manage protected areas in special-use forests, wetlands and marine areas. The strategy also identifies a set of strategic actions, including

- PA system planning
- Development of a legal framework for PA system management;
- Strengthening of natural resources management and biodiversity conservation;
- Reforming the organisation of the PA management system;
- Reforming procedures to establish, fund and invest in PAs;
- Training for human resource development, improvement of conservation knowledge and skills;
- Promoting information-education-communication and attracting community participation;
- Involvement in biodiversity conservation;
- Promoting international cooperation.

National Strategy for Environmental Protection Until 2010 and Vision toward 2020 identifies detailed objectives to ensure ecological balance at high level with the following targets:

- Recovering 50% of mining areas and 40% of severely degraded ecosystems;
- Increasing forest cover by 43% of total natural land, recovering 50% of degraded watershed forests and improving forest quality;
- Increasing total area of PNAs by half as much against current area, especially MPAs and wetland preserved areas;
- Recovering the area of mangrove forests by 80% as compared to 1990.

Government Decree No. 109/2003/ND-CP issued on 23 September 2003 addresses the conservation and sustainable development of wetlands. The Government requires establishing wetland reserves under strict protection regulations, including a prohibition of construction works and migration to the wetland sites. Buffer zones for wetland sites must be established, managed and be restricted with regard to exploitation, which would endanger the wetland sites conservation. The Decree identifies principles on conservation and sustainable use of wetlands; identifies detailed tasks on wetland management; and names the main state agencies involved in wetland management.

Circular no. 18/2004/TT-BTNMT dated August 23, 2004 guiding the implementation of the Government's Decree no. 109/2003/ND-CP of September 23, 2003 on conservation and sustainable development of wetlands. The Circular guides the conservation and sustainable development of wetlands with particular eco-systems and high biodiversity, among these those with functions of maintaining water sources or balancing the ecology, or those that are of international or national importance. For the conservation of wetlands, the circular identifies conservation criteria, conservation forms, institutional responsibilities for formulating projects to establish wetland reserves, management of wetland reserves, and the coordination of implementation activities.

The Viet Nam Biodiversity Action Plan (BAP) to the year 2010 and vision to the year 2020. One of the objectives identified under BAP is biodiversity conservation and development in wetlands and marine areas through:

- The increase of the total area of wetlands and marine reserves of national and international importance to over 1.2 million hectares.
- The restoration of 200,000 hectares of mangrove forests;
- The designation of five wetlands to be included in the list of wetlands of international importance (Ramsar sites).

Under major tasks, BAP identifies tasks for biodiversity conservation and development in wetlands and coastal areas, including:

- Building, developing and managing a wetlands and marine reserve system:
- Rehabilitating and developing wetlands and marine ecosystems:
- Sustainable use of wetlands and marine natural resources:

Decree 99 /2010/ND-CP on the Policy for Payment for Forest Environmental Services has identified principles of payment for forest environmental services as following:

- Organizations and individuals benefiting from forest environmental services must pay for forest environmental services to forest owners of forest that create the supplied services.
- Payment for forest environmental services is in money through direct or indirect payment methods.
- The payment for forest environmental services through a Forest Protection and Development Fund is the money that users of forest environmental services entrust the Fund to pay to owners of forests that supply forest environmental services.
- Payment for forest environmental services is factor of the production costs of products that use forest environmental services and does not substitute the resource tax or other payments stipulated by law.
- Transparency, democracy, subjectivity, and equity, in line with the legal system of Viet Nam and international agreements that Viet Nam ratifies or joins, are ensured.

It can be recognized that even wetland management is mentioned mostly in environmental strategies, but not in development plans. In addition, the system of policies and regulations on wetland management has not been completed or synchronised. Specific provisions in legal documents relating to wetlands and ecosystem management often overlap, and are also often scattered within different pieces of legislation. The most promulgated Decree 99/2010/ND-CP on the Policy for Payment for Forest Environmental Services has provided initial step for taking in consideration the value of ecosystem services through payment system. However, it is can be recognized that ecosystem services have not been considered in many sector development plans. Also, there is still a lack of scientific tools which can help policy makers to consider the value of ecosystem services.

Table 4: Comparison of Valuation Methods

Group	Methods	Summary	Statistical analysis?	Which services valued?
1. Direct market prices	Market prices	Observe market prices	Simple	Provisioning services
2. Market alternative	Replacement costs	Finding a man-made solution as an alternative to the ecosystem service	Simple	Pollination, water purification
	Damage cost avoided	How much spending was avoided because of the ecosystem service provided?	Simple	Damage mitigation, carbon sequestration
	Production function	How much is the value-added by the ecosystem service based on its input to production processes?	Complex	Water purification, freshwater availability, provisioning services
3. Surrogate markets	Hedonic Price Method	Consider housing market and the extra amount paid for higher environmental quality	Very complex	Use values only, recreation and leisure, air quality
	Travel Cost Method	Cost of visiting a site: travel costs (fares, car use etc.) and also value of leisure time expended	Complex	Use values only, recreation and leisure
4. Stated preference	Contingent valuation method	How much is the survey respondent willing-to-pay to have more of a particular ecosystem service?	Complex	All services
	Choice experiments	Given a 'menu' of options with differing levels of ecosystem services and differing costs, which is preferred?	Complex	All services
5. Participatory	Participatory environmental valuation	Asking members of a communityto determine the importance of a non-marketed ecosystem service relative to goods or services that are marketed	Simple	All services
6. Benefits transfer	Benefits transfer (mean value, adjusted mean value, benefit function)	'Borrowing' or transferring a value from an existing study to provide a ballpark estimate for current decision	Can be simple, can be complex	Whatever services were valued in the original study

Source: TEEB for local and Regional policymakers.

4. Mainstreaming of Wetland Ecosystem Services in Development Planning – Approach Methodology for Viet Nam

4.1. Tools for mainstreaming ecosystem services in development planning

There are number of tools which can apply to mainstream ecosystem services in to development planning. The following tools would be recommended to apply for Viet Nam:

1. Poverty and ecosystem service mapping overlays geo-referenced statistical information on poverty with spatial data on ecosystem services. The resulting maps can highlight important relationships, such as how the location of poverty compares with the distribution of services; which areas provide critically important services to the poor; who has access to natural resources; who benefits; and who bears the cost of changes to ecosystem services. Such overlays do not show causality, but suggest focus for further analysis.

2. Economic valuation assigns an economic value to ecosystem services that do not have a value in the market place, such as regulating and certain cultural services. The resulting information can draw attention to the value of ecosystem services that might otherwise be ignored when making decisions that affect ecosystems.

In general, economic valuation is effective in persuading decision makers of the value of ecosystem services by highlighting their economic contributions to societal goals; comparing the costs and benefits of ecosystem service protection versus engineering alternatives; and building markets for ecosystem services, such as global carbon markets or stewardship incentive programs for farmers.

3. Action Impact Matrix assesses the two-way interactions between development goals and ecosystems by exploring the effects of development goals on ecosystems as well as the effects of ecosystems on development. It can be used to determine economic, environmental, and social

Table 5: Entry Points for Mainstreaming Ecosystem Services[7]

Entry points	Ministry/Agency/Organization	Examples of decision processes
National and sub-national policies and plans	Development & planning	Poverty reduction strategies, land-use planning, water supply, and sanitation
	Environment	Protected area creation, climate adaptation strategies
	Treasury	National budgets, public expenditure reviews, audits
	Physical planning, emergency planning,and response	Integrated ecosystem management of coasts, river basins, forest landscapes, and watersheds
Economic and fiscal incentives	Finance	Subsidies, tax credits, payments for ecosystem services, import duties, and tariffs
	Budget office	Tax policies to support easements or promote alternative energy technology, pricing regulations for water
Sector policies and plans	Commerce and industry	Corporate codes of conduct/standards, assessment of new technologies
	Science and technology	Applied research, technology transfer, business capacity building
	Agriculture	Extension services, best management practices
	Forestry	Forest sector action programs, mapping initiatives, concession management
	Environment/ Natural resources	State of the environment reports, strategic environmental assessments, environmental impact assessments, information/ tools, legal instruments
Governance	Prime minister's or mayor's office, justice ministries, legislature, local government bodies	Decentralization policies, free press, civil society, accountability of government through elections, access to information and decisions, judicial review, performance indicators

[7] Ecosystem Services: A Guide for Decision Makers.

priorities that facilitate management and restoration of ecosystem services. The tool is best used as part of a participative process (Munasinghe 2007).

4.2. Entry Points for Mainstreaming Ecosystem Services

Many entry points are at the national or provincial level. Opportunities for mainstreaming ecosystem services can be categorized into four intersecting entry points: national and sub-national policies, economic and fiscal incentives, sector policies, and governance. Table 5 summarizes the key entry point for mainstreaming of ecosystem services with example of decision processes.

4.3 Mainstreaming ecosystem services in development planning for Viet Nam

Given specific characteristic of Wetland in Viet Nam, the following approaches/steps would be recommended for mainstreaming of ecosystem services in development planning for Viet Nam.

Identify ecosystem services of wetland, its current condititon and trend: The ecosystem services of variety type of wetland in Viet Nam should be understanded and economic valuation of wetland should be conducted as evidience for policy makers to select the best options in their decision. Different method would be applied to assess ecosystem services, including remote sensing, GIS, ecological models, participatory approaches, depending on different types of services.

Develop ecosystem Services Trade-off: It is necessary to develop trade-off matrix to understand the winners and losers of any options while utilization of ecosystem services which can help to select the optimum options and to minimize negative impacts to ecosystem services. Trade-off matrix can be developed to compare the linkages between economic development and ecosystem services or the trade-off among ecosystem services such as provision services and regulating services. Trade-off analysis can strengthen decision making processes in term of selecting the most appropriate options

Choose policies to sustain ecosystem services: There are number of entry for mainstreaming ecosystem services. At national level, Strategic Environmental Assessment would be appropriate tools for mainstreaming of ecosystem services in national socio-economic development strategies, planning and plans; planning for land use, forest protection and development in inter-provincial or inter-regional areas, etc.[8] SEA could be used as a tool for taking in consideration the drivers which have negative impacts on ecosystem services in sector planning to reduce its impacts. Focused sector for mainstreaming of ecosystem services would be land use planning, mining, fishery, and forestry. At local level, ecosystem services can be mainstreamed in local development planning such as protected area program, integrated coastal zone management program.

Fiscal reform would be alternative to mainstream of ecosystem services: Other options for sustainable use of ecosystem services would be development of economic and fiscal incentives such as establishing fees for use of resources or services and use taxes or other public funds to pay for the maintenance of regulating and cultural services. Beside payment for forest ecosystem services which has been mentioned in Decree 99 /2010/ND-CP, other environmental services of other wetland type, including inland and coastal wetland would be considered in development planning.

Mainstreaming of natural capital into national accounting system: Incorporating the value of ecosystem services as natural capital in to national accounting system would be other option for conserving the services in Viet Nam. Initial steps would be application of System of Economic-Environmental Accounts (SEEA) to include of natural capital in accounting system.

[8] These strategies/plans requires SEA before approval according to Law on Environmental Protection 2005.

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THE ROLE OF TREE CROPS IN LOCAL ADAPTATION TO CLIMATE VARIABILITY: LEARNING FROM THE FIELD

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Abstract

In the past decades, Yunnan Province in the southwest of the People's Republic of China has been frequently affected by floods and droughts as climate change impacts are increasingly felt. Based on studies in three villages in Baoshan Municipality, one of the foremost agricultural production areas in Yunnan Province, this paper presents the findings of the study "Too Much and Too Little Water" conducted by the International Centre for Integrated Mountain Development (ICIMOD), International Institute for Environment and Development (IIED) and Stockholm Environment Institute (SEI) together with the World Agroforestry Centre (ICRAF)/Kunming Institute of Botany (KIB), and explores agricultural diversification using trees on farms to support people's capacity to adapt to change, particularly climate-related changes, Results show that optimizing the integration of trees in agricultural landscapes as a tool for increasing adaptive capacity depends on tree crop diversification. In addition, a supportive policy environment is necessary.

1. Introduction

Climate change has had a particularly dramatic impact on ecosystem-based livelihoods, especially farmers engaged subsistence and small farm agriculture. One factor that contributes to household vulnerability is the use of monoculture production systems. Agricultural diversification, particularly when undertaken in relation to environmental or economic risks, has the potential to increase a household's adaptive capacity under climate change (Smit and Skinner, 2002). Diversification may also contribute to general agro-biodiversity and the sustenance of vital ecosystem structures and functions (Mijatovic, Paul Bordoni *et al*., 2010).

Agroforestry, the integration of trees into cultivated land, is an approach to agricultural diversification that can provide a range of benefits. It has been proposed as a strategy for climate change mitigation and adaptation as well as for addressing issues of food security and environmental degradation in agricultural systems. Agroforestry is gaining popularity as an adaptation strategy in part because traditional agricultural systems often include elements of agroforestry practices (Rafiq, Amacher *et al*. 2000; Liang, Shen *et al*. 2009). Thus, agroforestry can often be less costly and more efficient to implement than other approaches. However, with increasing market development, monoculture has replaced traditional agricultural diversification practices in some areas. Monoculture systems need to be re-examined for their viability in the context of climate change which will likely lead to changes that reflect growing uncertainty and increasing risks.

In the People's Republic of China (PRC), after severe droughts in 1997 and massive floods in 1998, on-farm tree planting or the "Sloping Land Conversion Program"(also known as the "Grain to Green Program"), was introduced to convert the croplands occurring on steep slopes to forested land in order to reduce water-induced disasters. These actions resulted from the realization that the droughts and floods were at least partially caused by farming on steep slopes and deforestation. This paper presents the findings of one of the case studies conducted in Baoshan Municipality, Yunnan Province, PRC, as part of the consolidated research "Too Much and Too Little Water" from four countries: the PRC, India, Nepal, and Pakistan. The paper focuses on the impact of water stress conditions and communities' coping responses.

2. Research Methodology

The study sites were in Yunnan Province in the PRC. Yunnan covers 394,000 km^2 and includes the headwaters of three of Asia's largest rivers. It is home to 46 million people, most of whom dwell in mountain regions. The montane geography creates a mosaic of settlement patterns, land use, and livelihood practices. Residents, including 25 distinct ethnic minority groups, have adapted in ways that demonstrate their local ecological knowledge and intimate relationship with the environment and climate.

For the study, three villages in Baoshan Municipality—Xinzhai, Shuiyan and Haitang—were selected for detailed study based on their diversity of elevation, climate, and

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agricultural systems (Map 1), additional details are provided in Table 1. Because a severe drought was affecting the study area during the research period, all the villages were experiencing extreme water shortages to different degrees and with different consequences in production and income. The Rapid Rural Appraisal included water source mapping with key informants.

In the first round of the study, we analyzed the response of communities and their vulnerability to climate change. We also documented local practices to cope with climate impacts, including information about community perceptions and observations on the impacts of climate change on tree crops and the role they play in adaptation. We also asked farmers why they plant trees, whether

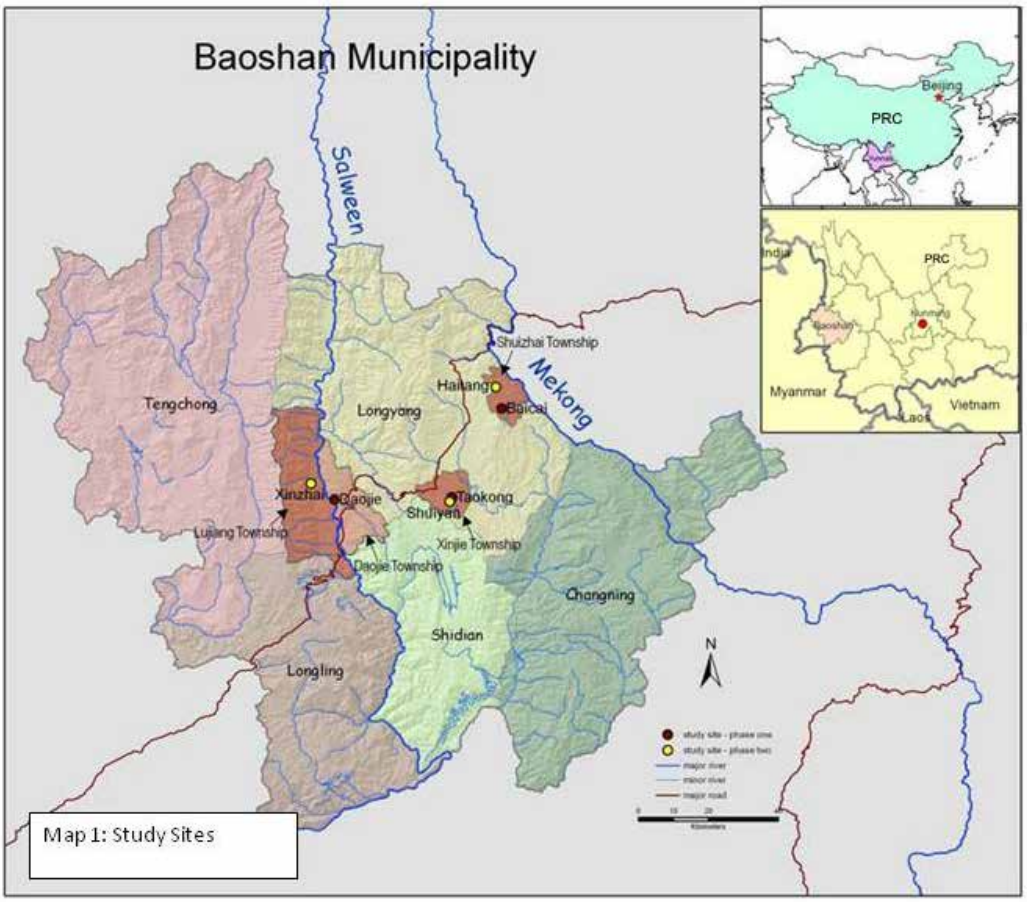


Table 1: Details of Study Sites

Location	Low levation	Middle levation	High elvation
Communities	Xinzhai	Shuiyan	Haitang
Elevation (m)	950	1,720	2,473
No. of households	545	560	371
Climate	Hot, low precipitation, high evaporation	Medium to warm temperature and medium evaporation	Low temperatures, high precipitation, and low evaporation
Temperature trend	Increasing	Increasing	Increasing
Major stress as perceived by the community	Water shortage in Spring & droughts	Water shortage in Spring and hail in Summer/ Autumn and droughts	Water shortage in Spring
Major crops on irrigated land	115 ha: coffee, paddy rice	50 ha: tobacco, paddy rice	Not applicable
Major crops on rain-fed land	155 ha: maize, coffee	112 ha: tobacco, maize, walnut, pear	116 ha: maize, barley, potato, beans, pepper, walnut
Population trends	Increasing	Increasing	Decreasing

existing policy and government programs support them, and how tree crops contribute to national adaptation strategies. These qualitative data were supported by quantitative data where relevant.

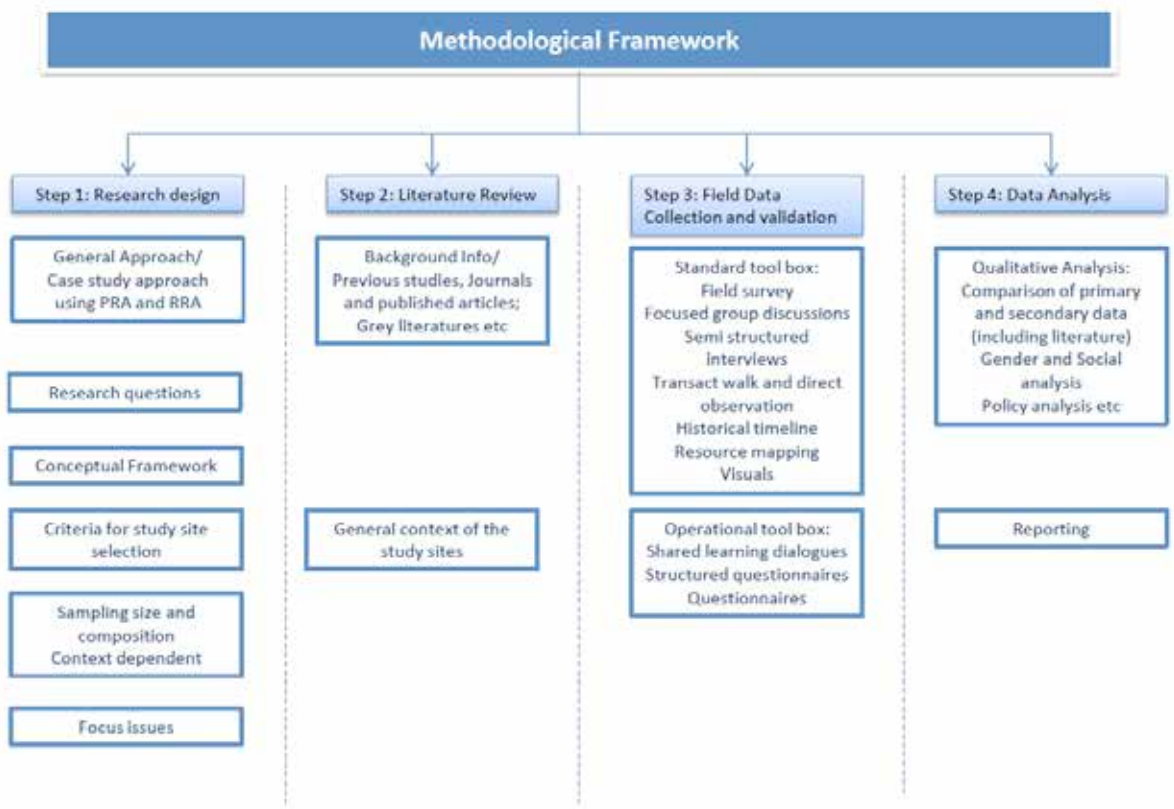
We discovered that most responses were oriented more toward short-term adaptation rather than long-term planned practices. We also found that policies always play a significant role in peoples' ability to respond to too much and too little water, even though the policies are, at times, unclear and weak in implementation. The capacity of formal and informal institutions also has to be enhanced to cope with and adapt to climate variability.

Building upon these findings, in the second round of research in Yunnan, we focused on agroforestry diversification. In this stage, secondary data on the role of trees on farms as an adaptation strategy were collected and analyzed. These data included related published literature, meteorological observations, government policies, event-related press releases and land-use and agricultural production data. Primary data were collected through rapid rural appraisals (RRA), questionnaire surveys involving key informants and group interviews, transect walks, crop calendars, and field observations (Figure 1). Sites were selected based on the representativeness of the major agro-ecosystems in the area, with consideration of the role of trees in local livelihoods, climate and elevation gradients, and the existence of water stresses and other climate change impacts. Questionnaire surveys of both males and females were carried out in three villages. Finally, quantitative analysis was undertaken using descriptive statistics and ANOVA tests in Microsoft Excel and SPSS.

3. Key Findings and Lessons

The drought experienced in Baoshan in 2009-2010 was the worst reported in 100 years. The impact on tree crops varied depending on the species and age; accordingly, the impact on households varied depending on the species. Different trees not only had different levels of resilience to drought in terms of yield, but functioned differently as long-term assets for households that invest in them. As farmers experience changes that may increase uncertainty and the risk of climate-related shocks, the impacts on production systems invite a re-examination of how they provide resilience against risk events and longer-term change.

Figure 1: Methodological Framework



Following are the key findings and lessons from the research. However, these findings cannot be generalized for all locations and weather conditions.

3.1 Agricultural Production Faces Increased Uncertainty and Risks Due to Climate Change and Variability

The findings of this study validate international and regional discourse that has found that the agricultural sector and livelihoods are most severely affected by climate change and variability (Hendow *et al*., 2007; Morton, 2007).

In most of the study areas, households depend on agriculture for their subsistence. The sources of irrigation for the agricultural fields are small springs and rivers, monsoon rains, snow melt, and small community irrigation systems. The agricultural sectors in the study areas were already impacted by extreme climatic situations, like flash floods and droughts, that reduced the crop yield and quality, whereas agroforestry systems were found to be more climate-resilient. For example, farmers estimated that walnut trees experienced a yield increase of 20%–30%, which enhanced the coping capacity of farmers and forestry workers.

In addition, farmers in both Haitang and Shuiyan observed that, of the walnut trees planted in 2007-08, only 10%–20% died in the 2009 drought, while of those planted in 2009, about 40%–50% died in the drought in 2010. However, nearly 100% of walnut trees planted five or more years ago survived the drought. Nearly all Sichuan pepper trees, very few of which were newly planted, survived.

3.2 Diversification of Crops, Including Tree Crops, Improved the Resilience of Communities; Monoculture Systems were More Vulnerable to Climatic and Nonclimatic Shocks

Results showed that during droughts, the three villages coped very differently. Although tobacco and grain crops were greatly affected by drought, the Government's extension program targeting tobacco growing areas in Shuiyan was successful in reducing the overall yield loss of tobacco. Also, the diversity of income sources, including non-timber forest products, and resilience of mature stands of walnut trees, meant that household incomes in Haitang were somewhat secure during the drought. However, due to the widespread failure of coffee crops that were the only source of income for the households in Xinzhai, people were forced to make emergency responses for survival, such as the purchase or rental of water pumps and migration of women and men for off-farm work opportunities.

Monoculture has, in the past, been encouraged because of immediate economic gains, but mountain communities are finding belatedly that reliance on monoculture plantations makes them extremely vulnerable to climate and economic shocks. Therefore, some farmers often look to diversification of crops and livelihoods as an adaptation strategy.

3.3 Adaptive Capacity of Communities is Driven more by Markets and Government Policy than by Awareness of Climate Change

The goal of the governments' Sloping Land Conversion Program was to convert 14.66 million hectares of farmland into forest land to reduce soil erosion. Likewise, Baoshan Municipal Government initiated an expansion of walnut production, with the goal of planting over 30,000 ha of walnut trees in the study area of Longyang District. The Government's policy, however, encouraged farmers to plant tree crops without considering climate resilience. Policies to invest heavily in a single tree crop without diversification fail to account for the impact of climate change and the variability of the single crop, which will have an impact on the income and livelihood of the people.

4. Conclusion and Policy Recommendations

We found that trees on farms play a varied role in farmers' response strategies under changing and increasing climate-related stresses. The benefits of trees depend on a number of factors and conditions often specific to the species. The main climate change-related threats include production systems and the local socioeconomic context. Results showed that integrating or expanding monoculture tree plantations may maintain or increase levels of vulnerability, while the use of multiple tree species often greatly improves resilience in agricultural systems and household livelihoods.

Policies to diversify tree crops and market incentives play strong roles in promoting the adoption of trees on farms. However, the study also showed that current markets and policies do not account for long-term climate changes and the possibility of increasing climate risks that

may affect the productivity and survival of trees. Without greater consideration of the impacts of climate change and climate variability on tree crops, communities will be unable to optimize the use of trees on farms for agricultural diversification or for enhancing their adaptive capacity.

We offer the following recommendations to strengthen the impact of national and local policies on adaptation to climate change:

- Revisit the effectiveness of existing and proposed policies and programs to strengthen adaptation strategies and ensure that they do not increase small holders' vulnerability to climate variability and climate risks.
- Allocate government resources to minimize vulnerability and risks and enhance household resilience.
- Document and analyze the knowledge of farmers, local extension workers, and scientists on the response of tree crops to climate change and vulnerability and develop tools to determine their potential to enhance resilience.
- Share information on the implications of climate change on agricultural systems and successful adaptation strategies that employ crop diversification.

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MANAGING CONCESSION FORESTS FOR CARBON BENEFITS IN CAMBODIA

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Abstract

The scheme to reduce emissions from deforestation and forest degradation, including conservation, sustainable management of forests, and enhancement of forest carbon stocks (REDD+) of the United Nations Framework Convention on Climate Change is a carbon-based compensation for projects that resulted in reducing carbon emissions or enhancing carbon sinks or both in tropical forests. However, estimating such emissions and sinks remains challenging, and thus making it impossible to estimate carbon revenues from managing tropical forests. Here, we estimated the reduced emissions and sinks by developing models for setting reference emission level (REL) and project emission level (PEL) for REDD+ projects in concession forests taking emissions under conventional logging (CVL) scenario as that of REL, and emissions under reduced impact logging (RIL) and RIL with liberation treatment (RIL+) scenarios as that of PEL. Cambodia logging was used as a case study. REL under the current 25-year cutting cycle was estimated at 23.1 teragrams of carbon dioxide ($TgCO_2$)/year$^-$. To determine an appropriate cutting cycle, we tested our models with four cutting cycles and found that a 50-year cutting cycle is more appropriate. Taking this 50-year cutting cycle as a REDD+ project, PELs were estimated at 0.4 $TgCO_2$ and –3.3 $TgCO_2$/year ("–" means a carbon sink) under RIL and RIL+, respectively. After subtracting REL with PEL and leakages, annual carbon credits from managing 3.4 million hectares of concession forests in Cambodia were estimated at 15.9-18.5 $TgCO_2$ depending on chosen scenario. At a carbon price of $5 per megagram of CO_2, total revenues from the sales of carbon credits alone would be $79.5-92.5 million annually. To ensure continued flow of wood supply from tropical forests while mitigating climate change, we suggest that new climate agreements adopt RIL or RIL+ for sustainable forest management in tropical countries.

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1. Introduction

Negotiations for new climate agreements were to be discussed at the 17th Conference of the Parties (COP17) of the United Nations Framework Convention on Climate Change (UNFCCC) in Durban, South Africa in December 2011. Among the expected agreements were the financial incentives for mitigating climate change through reduced emissions from deforestation and forest degradation, improving forest conservation and sustainable forest management, and enhancing carbon sinks or the "REDD+" scheme. REDD+ is an attractive option because it is less expensive (van Kooten *et al*., 2004; Kindermann *et al*., 2008; Sasaki and Yoshimoto, 2010) than other options being taken under the Kyoto Protocol. In addition, it contributes directly to improving the livelihood of forest-dependent communities and therefore helps to achieve sustainable development of poor nations, while still contributing to mitigating global climate change (Houghton, 2003; Gullison *et al*., 2007). The anticipated REDD+ agreements have also attracted increasing research to estimate the carbon emission reductions and the associated costs of implementing the specified management activities, and how such emission reductions can be monitored and verified. Recent data suggest that between 2000 and 2009, land-use change (mostly tropical deforestation) was responsible for the release of 1.1±0.7 petagrams of carbon (Pg C) (about 4 billion tonnes of carbon dioxide [CO_2]) (Friedlingstein *et al*., 2010). Kindermann *et al*. (2008) suggest that 50% of carbon emissions from tropical deforestation could be halted at carbon prices of $5.20-38.15 per megagram (Mg) of CO_2 (tonne CO_2) varying by continent.

Sasaki and Yoshimoto (2010) focused on the opportunity costs of managing tropical forests versus clearing these forests to develop industrial plantations, and suggested that managing tropical forests for timber production under the REDD+ mechanism would be preferable because of the huge potential revenues and other benefits from the ecosystem services provided by these forests. Toni (2011) suggests the need for REDD+ decentralization in order to effectively manage the revenues from REDD+ scheme while protecting tropical forests. Although previous studies clarified the fundamental basis for understanding the potential of REDD+, many failed to address the potential reductions in carbon emissions and the timber supply from sustainably managing concession forests. Estimating emission reduction potentials requires an understanding of the reference emission level (REL: emissions in the absence of project activities) and the project emission level

(PEL: emissions from project implementation) (Ty *et al*., 2011).

Sustainable forest management (SFM) is an important part of REDD+, because it maintains wood supply from the forests to meet increasing demands for wood while generating employment and revenues for owners of the forest resource or for governments in developing countries. SFM is strongly affected by logging practices (Pearce *et al*., 2003; Asner *et al*., 2006; Sasaki and Putz, 2009), and logging practices are generally carried out by logging companies or concessionaires in the tropics. If SFM is finally included in the REDD+ scheme under the new climate change agreements, a sound management system is required for managing concessions because the current logging practices have been responsible for rapid forest degradation and deforestation (Asner *et al*., 2006; 2010). Furthermore, logging practices strongly influence the end-use wood supply and carbon stocks in concession forests in the tropics (Sist *et al*., 2003; Kim Phat *et al*., 2004; Sasaki, 2006) , it is therefore necessary to understand which logging systems are both sustainable and economical.

To better inform policy makers as well as negotiators of the REDD+ scheme, there is critical need for developing methods for estimating the REL and PEL. Until recently, there was no agreed-upon method for estimating them (Sist *et al*., 2003), especially for REDD+ projects leading to reduced forest degradation and/or enhancing carbon sinks in concession forests where commercial logging for hard currency earnings is being practiced. Aiming at proposing an appropriate system for managing tropical forests under the anticipated REDD+ scheme, we analyzed the potential of carbon emission reductions from managing concession forests while maintaining a continuous supply of end-use wood products from concession forests in Cambodia.

2. Study Methods

2.1. Concession forests

Natural forests in the tropics are commonly managed under a forest concession system, in which the government as the forest resource owner issues logging licenses to logging companies, i.e., forest concessionaires, to harvest the timber as per guidelines and laws of the country. In 2006, Cambodia had a total forest cover of 10.7 million ha or about 59% of the country's total land area (Forestry Administration, 2008). Deforestation rate was estimated at about 0.7% between 1973 and 2003 (Sasaki, 2006) and about 0.8% between 2002 and 2006 (Forestry Administration, 2008). There are three major forest types in Cambodia, namely evergreen, semi-evergreen, and deciduous forests. Other forest types include inundated and mangrove forests and forest plantations, but these represent only a small proportion of the total forest cover. The annual rate of loss of evergreen, semi-evergreen, and deciduous forest was about 0.35%, 1.59%, and 0.73%, respectively, between 2002 and 2006. Of the 10.7 million ha, concession, protection, and conversion forests account for 36.1%, 43.1%, and 20.8%, respectively. The 3.4 million ha of concession forests are under the jurisdiction of the Forestry Administration of the Ministry of Agriculture, Forestry, and Fisheries (MAFF). Prior to a logging ban in early 2002, a 25-year selective cutting cycle was used for managing concession forests in Cambodia. We used this cycle as our business-as-usual cutting cycle.

2.2. Management Scenarios

Almost all logging practices in the tropics are carried out with little or no proper management plan or trained staff (Putz *et al*., 2008; Sasaki *et al*., 2011). Such logging is termed here as conventional logging (CVL)—logging practices that require neither formal planning nor trained staff. CVL causes much damage to the residual stands and wastes large amounts of wood, both in the forest and at the sawmill or pulp and paper plant (Holmes *et al*., 2002). In contrast is reduced-impact logging (RIL) management. A management scenario that includes RIL and a "liberation" treatment is termed RIL+. RIL involves proper training of logging staff; well-defined logging plans; careful planning of main, secondary, and feeder road locations before harvesting and extraction; directional felling; cutting stumps low to the ground; minimizing wood waste caused by felling, skidding, and road transportation; minimizing road and trail widths; minimizing landing size and maximizing landing spacing; minimizing ground disturbance; paying attention to forest aesthetics; and minimizing damage to the residual stand. Holmes *et al*. (2002) and Sasaki and Putz (2009) provide more details about RIL practices. RIL is a promising logging practice for managing tropical forests (Putz *et al*., 2008) because it involves careful planning to minimize waste and adverse impacts on the residual stand. RIL+ additionally uses a liberation silvicultural treatment, in which unwanted trees that are competing with future crop trees are girdled to kill them. By reducing the competition from unwanted trees, growth rates of the crop trees can be increased by 20%–

60% compared with the growth rate in forests where only RIL is implemented (Peña-Claros *et al*., 2008; Villegas *et al*., 2009).

2.3. Carbon Stock Changes

We describe the changes in the above-ground carbon stocks per hectare in tropical forest under the CVL, RIL, and RIL+ approaches using the following modified equations of Kim Phat *et al*. (2004):

$$\frac{dCS_i(t)}{dt} = MAI - [LM_i(t) - H_i(t)] \times BEF \quad (1)$$

$$H_i(t) = \frac{f_M \times f_H}{1 - r} \times \frac{CS_i(t)}{T_c \times BEF} \quad (2)$$

where:

$CS_i(t)$: aboveground carbon stock (megagrams of carbon per hectare [Mg C ha^{-1}]) under logging system i (where i is CVL, RIL, or RIL+) in year t. It is assumed that forest management starts in 2010, and therefore t_0 is corresponding to 2010, the start of the simulation

MAI: mean annual increment (MgC ha^{-1} year^{-1})

$LM_i(t)$: carbon in dead trees lost due to logging-induced mortality (Mg C ha^{-1} year^{-1})

$H_i(t)$: harvested carbon (Mg C ha^{-1} year^{-1})

BEF: biomass expansion factor (ratio of total aboveground biomass to stem biomass)

f_M: proportion of mature trees

f_H: legal rate of harvesting permitted by the government

r: rate of illegal logging

T_c: cutting cycle (years). To determine an appropriate logging cycle for managing concession forests in Cambodia, four cutting cycles, namely 25 years (previously adopted cycle), 40 years, 50 years, and 60 years.

2.4. Wood Products Model

Under both logging systems, we calculated the quantities of the following wood components: wood products (WP), wood waste (WAS), logging mortality (LM), end-use wood products (EWP), and end-use wood waste at sawmill or pulp and paper mill (EWAS) using the following equations:

$$WP_i(t) = (1 - s_i) \times H_i(t) \quad (3)$$

$$WAS_i(t) = H_i(t) - WP_i(t) \quad (4)$$

$$LM_i(t) = \alpha \times H_i(t) \quad (5)$$

$$EWP_i(t) = (1 - a_i) \times WP_i(t) \quad (6)$$

$$EWAS_i(t) = WP_i(t) - EWP_i(t) \quad (7)$$

where:

s_i: proportion of unusable wood after deducting losses due to logging, skidding, and damage during transportation

Table 1. Parameters, Assumptions, and Sources of Data

Description	CVL	RIL	RIL+	Sources
CS(0)	134.01	134.01	134.01	Average from Kao and Iida (2003), Kim Phat *et al*. (2004), Sist and Saridan (1998), Chave *et al*. (2005), Wellhöfer (2002), and Nascimentoa and Laurance (2002)
f_M	0.50	0.50	0.50	Kim Phat *et al*. (2004)
f_H	0.30	0.30	0.30	Kim Phat *et al*. (2004)
r	0.50	not applicable as explained in equation (11)		Assumed based on Kim Phat *et al*. (2004)
T_c	25	25	25	Practiced in Cambodia until logging was banned in 2002
MAI (Mean Annual Increment)	0.66	0.66	0.99[1)]	Elsewhere in tropics 0.64 reported in Lewis *et al*. (2009) and 0.72 reported in Phillips *et al*. (1998) [1)]: assumed 50% increase in MAI based on Peña-Claros *et al*. (2008) and Villegas *et al*. (2009)
BEF	1.74	1.74	1.74	Brown (1997)
α	1.0[2)]	0.5[3)]	0.5[3)]	proportion of H(t) [2)]: see Kim Phat *et al*. (2004) for more explanation [3)]: based on Chheng (2011)
s (WAS)	0.30	0.10	0.10	30% waste for CVL, and 10% for RIL. See Kim Phat *et al*. (2004) for details
Wood waste due to processing				
a (EWAS)	0.50	0.40	0.40	50% waste for CVL, 40% for RIL (see Kim *et al*., 2006)

under system i (CVL, RIL, or RIL+)
α: proportion of trees killed by logging, log skidding
a_i: wood processing efficiency (wood recovery) under system i
The units of WP, WAS, LM, EWP and EWAS are Mg C ha^{-1} $year^{-1}$, otherwise stated

2.5. Maintaining the End-use Wood Supply

Sustainable forest management cannot be achieved if maintaining a long-term sustainable wood supply is not part of the management goals. In this analysis, we assumed that the EWP produced under the CVL system is a baseline against which the EWPs from RIL and RIL+ are compared. Therefore, the EWPs from both logging practices must be equal:

$$EWP_{CVL}(t) = (1 - a_{CVL}) \times WP_{CVL}(t) \quad (8)$$

$$EWP_R(t) = (1 - a_R) \times WP_R(t) \quad (9)$$

where the subscript "R" means that the equation can be used for both RIL and RIL+.

To maintain a long-term wood supply under the REDD+ scenario (using RIL or RIL+) that is comparable to that under the baseline scenario (using CVL), the wood supply under CVL must be maintained:

$$EWP_R(t) = EWP_{CVL}(t) \quad (10)$$

or

$$H_R(t) = \frac{(1 - a_{CVL})(1 - S_{CVL})}{(1 - a_R)(1 - S_R)} \times H_{CVL}(t) \quad (11)$$

This study only includes above-ground carbon stocks. Below-ground carbon and carbon fluxes in various harvested wood products are not accounted for.

2.6. Reference Emission Level, Project Emission Level, and Carbon Crediting

Crediting reduced carbon emissions (carbon credits) requires the understanding of at least three important variables: reference emission level (REL) or baseline emissions or emissions in the absence of project activities, project emission level (PEL) or emissions resulted from implementing the projects, and leakages (L) or the emissions outside the project boundaries. Until recently, there was an agreed formula for determining REL, PEL or L (Angelsen, 2008). As the REDD+ scheme is performance-based compensation for reduced carbon emissions or sinks resulting from project activities, we developed equations for estimating carbon credits from project implementation in concession forests in the tropics. Carbon credits can be derived by:

$$CC(t) = REL(t) - PEL(t) - L(t) - EP(t) \quad (12)$$

$$REL(t) = [CS_{CVL}(t) - CS_{CVL}(t-1)] \times 3.67 \quad (13)$$

$$PEL(t) = [CS_{RIL}(t) - CS_{RIL}(t-1)] \times 3.67 \quad (14)$$

$$PEL(t) = [CS_{RIL}(t) - CS_{RIL+}(t-1)] \times 3.67 \quad (15)$$

where:
CC: Carbon credits
REL(t): Reference emission level at year t ($TgCO_2$ $year^{-1}$). Emissions under the conventional logging (CVL) scenario is taken as baseline emissions
PEL(t): Project emission level at year t ($TgCO_2$ $year^{-1}$)
L(t): Leakages or carbon emissions outside project boundary ($TgCO_2$ $year^{-1}$). L in forestry project is difficult to estimate but Murray *et al.* (2002) found that L varies greatly from one location to another. For simplicity, 30% is assumed for L for our study.
EP(t): Emissions from project's fieldwork activities such as emissions from logging operations and wood transportation. According to UNFCCC (2008), emissions that account for 10% or less of the overall emissions can be excluded from the calculation. Therefore, we excluded EP in our carbon credits calculation because it is unlikely that EP is more than 10% of the overall emissions
$CS_{CVL}(t)$, $CS_{RIL}(t)$, $CS_{RIL}+(t)$: Carbon stocks in the year t under CVL, RIL, and RIL+ scenarios, respectively (TgC)
3.67=44/12: is the ratio of the molecular weight of CO_2 (44) to the molecular weight of carbon (12)

If PEL=0, the project neither generates carbon sinks nor source. If PEL(t) < 0, the project generates sinks from the applications of RIL or RIL+ because their application can reduce harvested wood, thereby reducing damage to residual stands, while still maintaining the wood supply equivalent to that under the business-as-usual scenario; e.g., under conventional logging. If PEL(t)>0, the project generates sources. But, as long as PEL(t) < REL(t), "additionality" or "carbon credits" can still be achieved.

2.7. Wood Products and Overall Carbon Stocks

Total wood products and carbon stocks for each scenario from managing 3.4 million ha of concession forests in Cambodia are the products of respective variables and area of concession forests.

3. Results and Discussion

3.1. End-use Wood Products and Wood Wastes

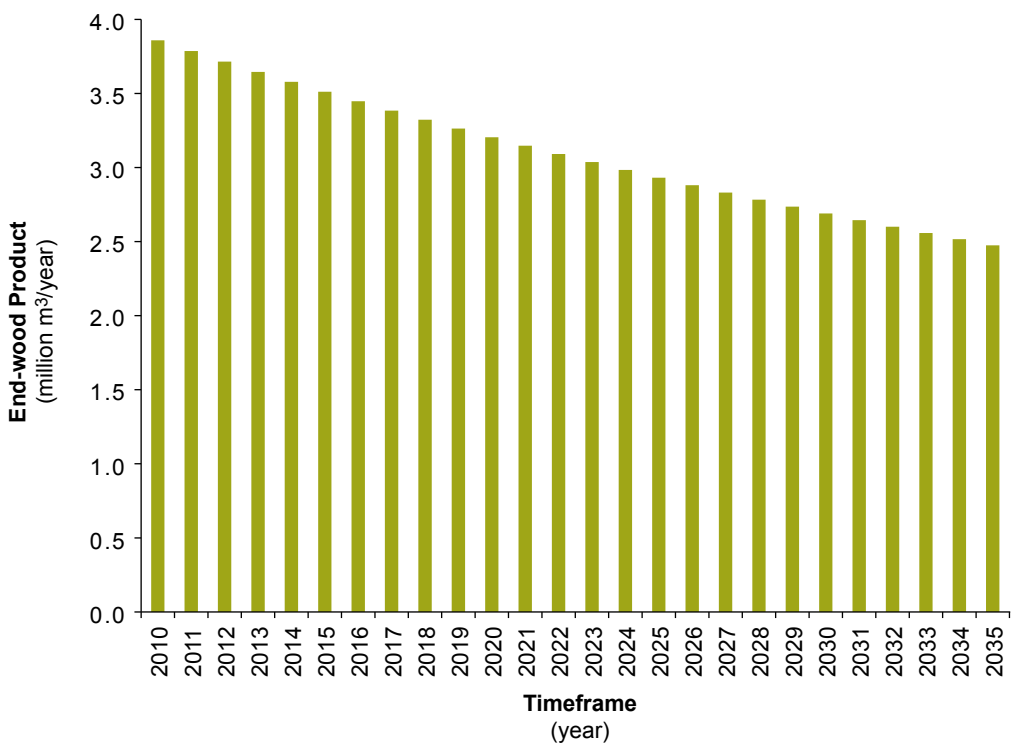
The study assumes that the demand of end-use wood products is equivalent to that produced under the conventional logging scenario (Equation 10), regardless of the source of end-use wood products, due to the lack of information on actual timber demand and supply in Cambodia. The supply is maintained under the RIL and RIL+ scenarios. Under the cutting cycle of 25 years for all three management scenarios, managing 3.4 million ha of concession forests in Cambodia produces, on average, 3.1 million cubic meters (m^3) per year of end-use wood products, but at a declining rate of 1.8% annually over the entire 25-year period (Figure 1). In terms of wood wastes (on-site and at the sawmill), CVL creates 5.8 million m^3/year over the same period, while only 2.6 million m^3/year of wastes are created under the RIL (including RIL and RIL+) or less than half that created by CVL. Wood wastes under CVL result from unprofessional logging, log skidding, trimming and transporting, and wastes at the sawmill.

Illegal logging strongly influences the quantities of end-use wood products and carbon stocks in the forests. If half of the wood from illegal logging is eliminated (r= 0.5/2), wood supply is maintained at 2.3 million m^3/year but rate of decline is about 1.0%. If illegal logging is completely eliminated (r = 0), wood supply is maintained at 1.8 million m3/year while the rate of decline is only about 0.7%. Our estimates are well within wood production estimates of the World Bank *et al*. (1996) and DAI (1998) who reported annual wood production (including illegal production) to be 1.5–4.3 million m3 from 1995 to 1997.

3.2. Carbon Stock Changes

Our models suggest that under CVL, total carbon stocks in 3.4 million ha of concession forests decrease from 455.6 teragrams of carbon (Tg C) at the start of the management (t = 0) to 292.2 Tg C at the 25th year (the end of the cutting cycle, t = 25), representing an annual degradation (emissions) of 6.5 Tg C or 23.9 Tg CO_2 (1 Tg CO_2 = 1 million tonnes CO_2) or 1.4% annually. Under the RIL and RIL+, carbon stocks also decrease from 455.6 Tg C and 455.6 Tg C at t=0, respectively, to 403.4 and 428.2 Tg C at t = 25, representing an annual degradation of 14.7 Tg CO_2 (0.9%) and 11.4 Tg CO_2 (0.5%) over a 25-year cutting cycle (Figure 2).

Figure 1: Volume of Annual End-Use Wood Products under Three Management Scenarios over a 25-Year Period



Illegal logging also strongly affects carbon stocks in the forests. If half of the rate of illegal logging used in our study is halted, annual carbon loss (degradation) is 15.3 Tg CO_2, 8.0 Tg CO_2, and 4.4 Tg CO_2 under CVL, RIL, and RIL+ scenarios, respectively. If illegal logging is completely eliminated, these scenarios result in annual carbon loss (degradation) of 10.2, 4.3, and 0.6 Tg CO_2, respectively over the 25-year cutting cycle (Figure 3).

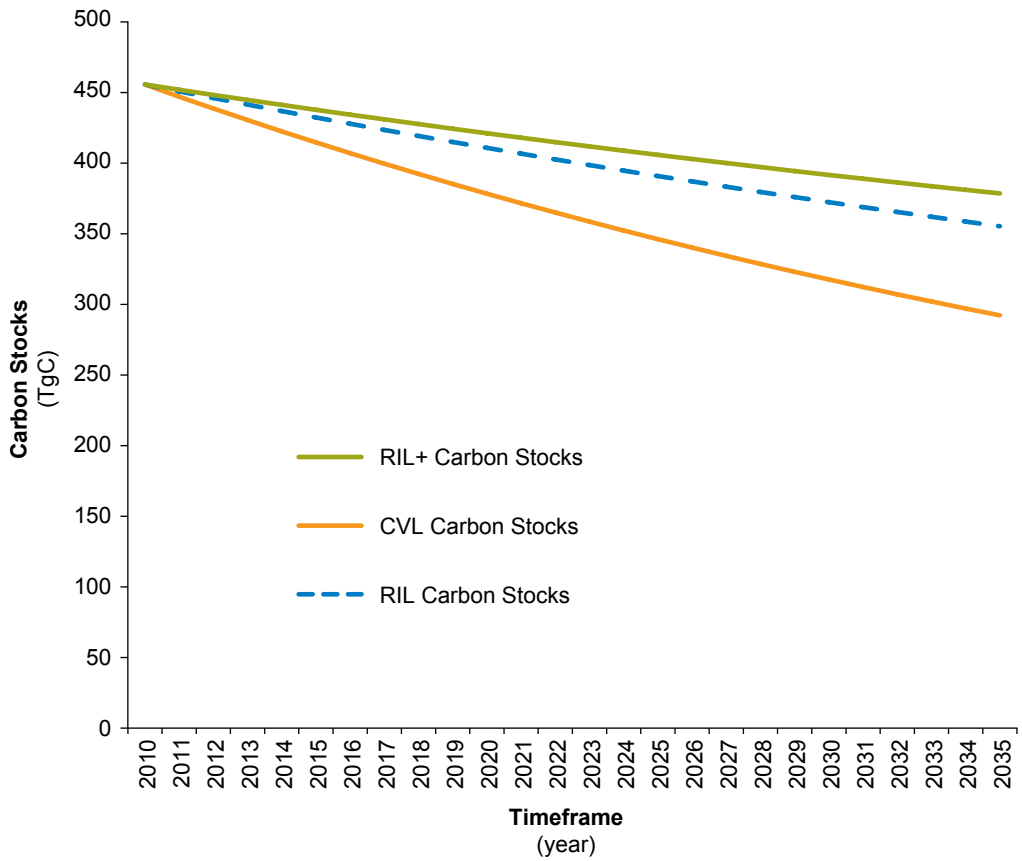
Previous studies on avoiding emissions from forest degradation through managing concession forests are very limited and difficult to compare with our study. Asner *et al*. (2009, 2010) found that at least 20% of tropical forests were under various forms of selective logging; forest degradation in the Amazon doubled during the 2000s. Conventional logging caused rapid deforestation in the Amazon, where 16% of selectively logged areas were deforested within a year of logging, with a subsequent annual deforestation rate of 5.4% for 4 years after timber harvests (Asner *et al*., 2006).

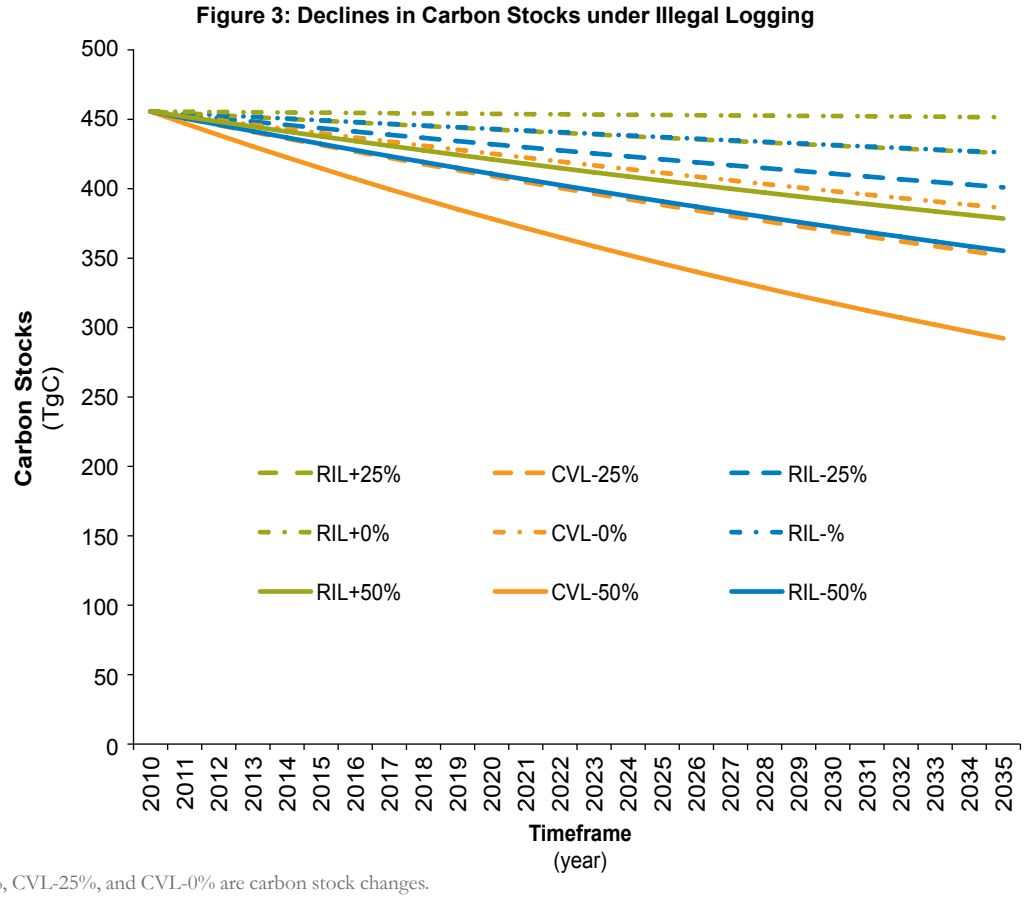
3.3. Appropriate Management System

In order to determine the appropriate management system to maintain a sustainable supply of end-use wood products from managing concession forests in Cambodia, three more cutting cycles were tested under the three management scenarios with three rates of illegal logging, namely 50%, 25%, and zero. The results (Figure 4) indicate that the annual volume of end-use wood product from 3.4 million ha of concession forests would be about 1.08 million m^3, increasing 0.06% annually under a 60-year cutting cycle when illegal logging is reduced to 25% (Table 2). If illegal logging is completely eliminated, a 40-year cutting cycle would ensure the sustainable supply of end-use wood product of 1.21 million m^3 under RIL or RIL+ practices.

Given the nature of illegal logging and governance problems in developing countries, it is unlikely that illegal logging can be completely eliminated. Taking into account the need for investment return, a cutting cycle of between 40 and 60 years would be appropriate. Cutting cycles

Figure 2: Decline in Carbon Stocks under the Three Management Scenarios over a 25-Year Cutting Cycle





Note: CVL-50%, CVL-25%, and CVL-0% are carbon stock changes.

Table 2. Average Annual End-Use Wood Product Volume under 4 Cutting Cycles and 3 Rates of Illegal Logging

Cutting Cycle	Illegal logging rate: 50%		Illegal logging rate: 25%		Illegal logging rate: 0%	
(year)	(million m³)	(%)	(million m³)	(%)	(million m³)	(%)
25	3.41	-0.88	2.41	-0.48	1.86	-0.26
40	2.28	-0.43	1.58	-0.15	1.21	0.00
50	1.86	-0.26	1.28	-0.03	0.98	0.10
60	1.58	-0.15	1.08	0.06	0.82	0.16

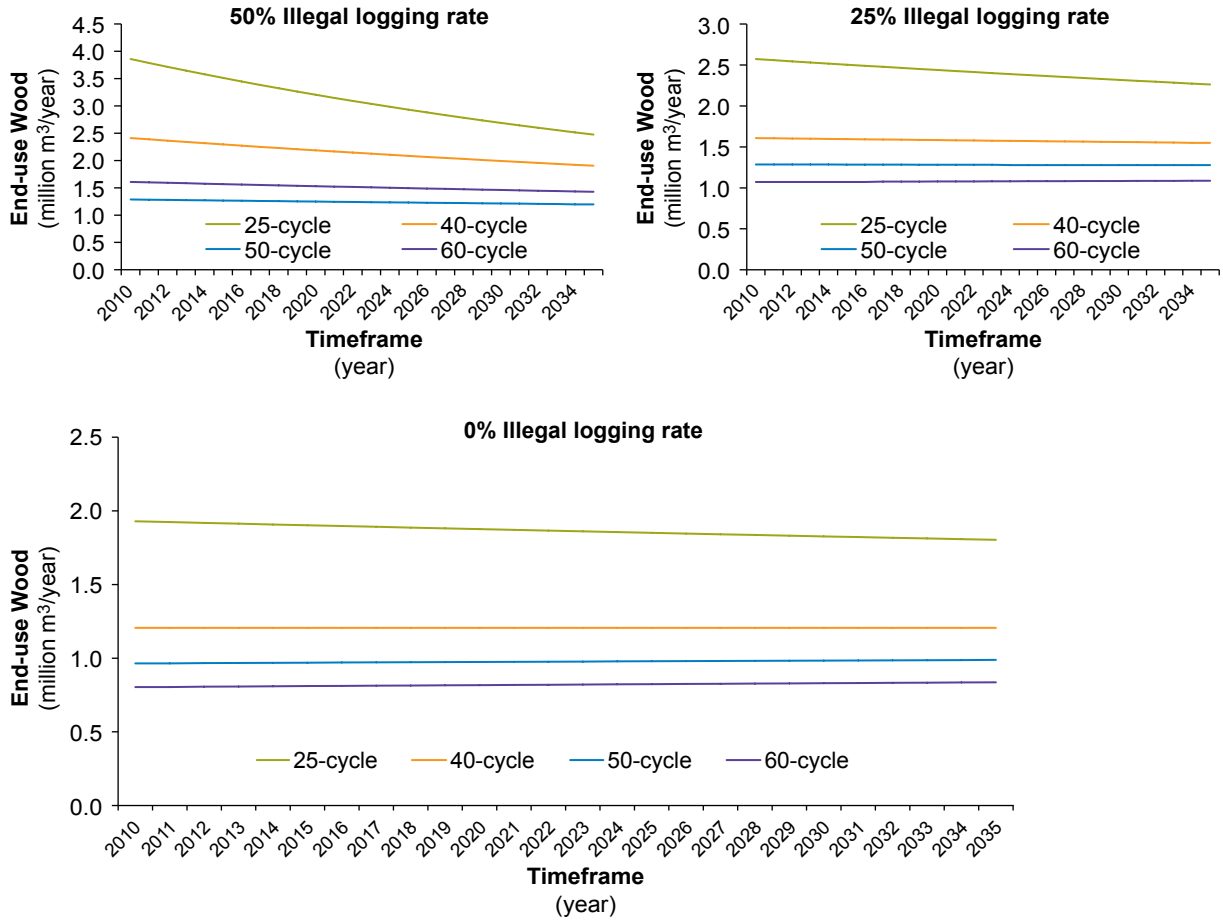
Note: Values in this table are the average for 25-year modeling timeframe.

that are shorter than 40 years cannot ensure a long-term sustainable supply of end-use product. The results also indicate that short cutting cycles coupled with illegal logging would produce high production of end-use wood but on a sharply declining basis as shown in Figure 4. Countries with unstable political situations are likely to adopt the short cutting cycles for immediate financial gains at the expense of forest resources and carbon stocks. Such practices have been the cause of rapid forest degradation and deforestation in the tropics during recent decades (Casson and Obidzinski, 2002).

Taking into account past experience with illegal logging and governance and the inability to completely reduce illegal logging, a 50-year cutting cycle with 25% rate of illegal logging is more realistic, and therefore appropriate for managing forests under the REDD+ scheme.

Liberation treatment should be used with precaution since only two experiments have been done so far (Peña-Claros *et al*. [2008]; Villegas *et al.* [2009]). This practice should be carefully undertaken by well-trained professionals who have knowledge about tree species and their interactions with other organisms in the forests. Otherwise, only highly commercial tree species will be left to grow at the expense of other species and tree-dependent biodiversity.

Figure 4: Supply of End-Use Wood Products under Four Cutting Cycles with and without Illegal Logging



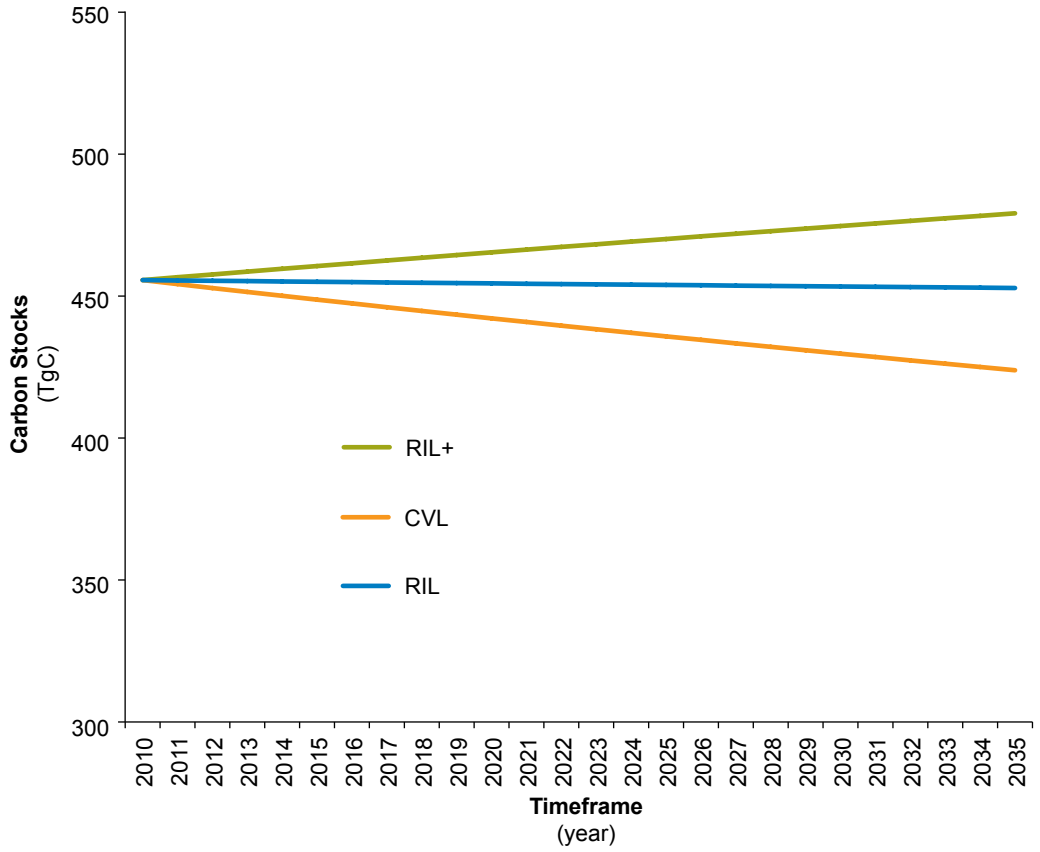
3.4. Reference Emission Level, Project Emission Level, and Carbon Credits

By taking a 50-year cutting cycle as the basis of a REDD+ scheme, REL, PEL and carbon credits can be determined. Assumed that the first carbon crediting period is 25 years (half of the cutting cycle) and the project is able to reduce the current rate of illegal logging to 25%, carbon stocks under CVL, RIL, and RIL+ scenarios are 455.6 Tg C at the beginning of the management (t = 0) and 423.9, 452.9, and 479.2 Tg C, and 499.5 Tg C at the 25th year (end of first crediting period), respectively, declining 1.3 Tg C (0.3%), 0.1 Tg C (0%), and -0.9 Tg C (-0.2%) (Figure 5). (By conventional, minus '-' indicates a carbon sink).

With the above assumptions (25-year carbon crediting period, 50-year cutting cycle, 25% rate of illegal logging), two types of REL can be argued, namely REL under the CVL with a 25-year cutting cycle and REL under CVL with a 50-year cutting cycle. REL under the latter is unlikely because it is a proposed practice for the RIL or RIL+ system that would be adopted for future REDD+ projects in concession forests (Sasaki, 2010). Therefore, we chose REL under CVL with a 25-year cutting cycle for comparison in our study. REL and PEL were estimated at zero at beginning of the project (t = 0). At the second year, REL increased to 31.5 Tg CO_2, then decreased to 17.7 Tg CO_2 by year 25 of the project implementation. This decrease is caused by the decrease of available timber for harvesting. On average over the first crediting period, REL was estimated at 23.1 Tg CO_2/year.

PEL increased to 0.4 Tg CO_2 and –3.7 Tg CO_2 at the second year, respectively under RIL and RIL+ scenarios. PEL remained constant at 0.4 Tg CO_2 under RIL but slowly declined to –3.2 Tg CO_2 under RIL+ at the 25th year of project implementation (Figure 6). Average PELs were 0.4 Tg CO_2/year and -3.3 Tg CO_2/year under RIL and RIL+, respectively. After subtracting 30% from [REL(t)-PEL(t)], annual carbon credits under the RIL or RIL+ were estimated at about 15.9 Tg CO_2 or 18.5 Tg CO_2 under RIL and RIL+ scenarios, respectively. If carbon is priced at $5

Figure 5: Carbon Stocks under a 50-Year Cutting Cycle with 25% Rate of Illegal Logging in Concession Forests in Cambodia in the First Crediting Period



(average carbon price at the voluntary carbon market was \$7.88 per Mg CO_2, ranging from \$0.67 to \$50 [Hamilton *et al*., 2009]), total annual carbon-based revenues from managing 3.4 million ha of concession forests would be \$79.5 million under RIL to \$92.5 million under RIL+. In addition to these carbon-based revenues, revenues from timber royalties and other benefits from long-term management of concession forests can also be obtained. The carbon-based revenues alone are more than 4 times higher than the timber revenues from logging in Cambodia reported in 1995 (Chheng, 2011).

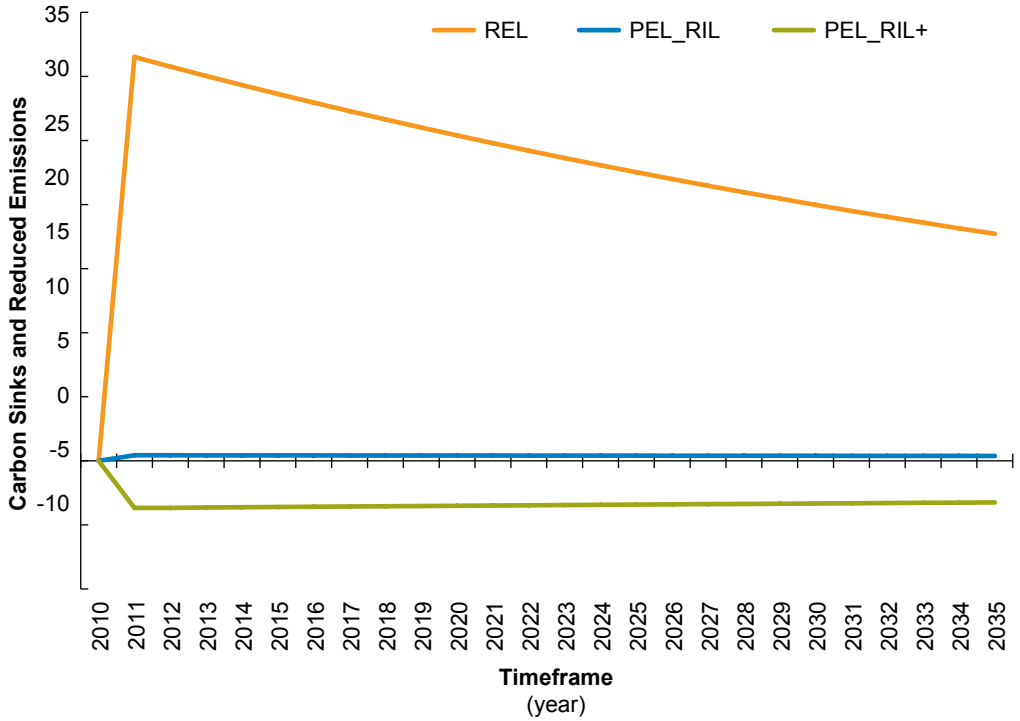
Logging costs had been generally thought to be expensive under the RIL or RIL+ options; however, based on various studies in the tropics, Sasaki *et al*. (2011) argued that costs are not expensive as previously thought. However, cost-effective analysis is beyond the scope of this paper.

4. Conclusions

We developed methods to estimate REL, PEL, and carbon credits for REDD+ projects in tropical forests under three management scenarios: management under conventional logging, reduced impact logging (RIL) and RIL with liberation treatment (RIL+). Carbon credits generated from the REDD+ projects are huge and would be attractive to project developers if there are continued financial incentives and/or carbon markets for such credits. The inclusion of the REDD+ scheme in the new reduction mechanisms for post-Kyoto project implementation will ensure such incentives and carbon market.

Our results suggest that the 25-year cutting cycle practiced in Cambodia is too short to sustain the flow of end-use wood production. A 50-year cutting cycle under reduced-impact logging (RIL) or RIL with liberation treatment (RIL+) could maintain a permanent supply of end-use wood products but at a lower rate than that under conventional logging with a shorter-term cutting cycle. Achieving sustainable

Figure 6: Reference Emission Level and Enhanced Carbon Sinks



Note: PEL_RIL and PEL_RIL+ are project emission levels under the RIL and RIL+ scenarios.

forest management under the REDD+ mechanism will require the adoption of sound logging practices that will reduce damage to residual forest stands and the soils that sustain these stands, and that will reduce disturbances to upstream resources (e.g., forests that protect catchment ecosystem services) while maintaining a continuous flow of end-use wood products. Without such carbon-based incentives, RIL+ will not be adopted and emissions from logging cannot be avoided, putting efforts to mitigate climate change and achieve sustainable development in developing countries at risk.

Financing currently made available from fast-start climate finance sources should also be used for capacity building on RIL or RIL+ for effective implementation when the REDD+ scheme becomes an international binding agreement—under which RIL or RIL+ will be required for managing tropical forests. For RIL+, precautionary measures should be taken to prevent the killing of commercially less important but biologically important tree species.

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FORESTS, PAST, PRESENT AND FUTURE IN THE GMS

Alastair Fraser[1]

Abstract

Inappropriate policies in relation to land, market, employment, environment, and governance issues have been major contributory factors to continued destruction and degradation of forests throughout the subregion, according to a 2001 report. The report also showed that the value of forests was generally very much underestimated because of lack of appreciation of the economic and environmental costs of destroying forests, leading to market distortions that have contributed to forest degradation and destruction. Little if anything has changed over the past decade. The same issues still predominate, although the rise of Reducing Emissions from Deforestation and Forest Degradation (REDD+) has focused attention on the issues and may yet achieve some action.

The forestry sector provides a number of investment opportunities that can greatly contribute to poverty reduction. Realizing these opportunities is not dependent on an existing forest resource, since the demand for forest products and services is strong, even in countries with little or no natural forest, and can be largely met by establishing plantations.

Sustainable forest management will require a stable resource base and countries need to have land-use plans that determines as far as possible, the balance between the alternative uses, that brings the greatest overall benefit. Under-valuation of forest resources promotes wasteful use, illegal logging, and corruption and results in reduced government revenue.

Low political priority for forestry has generally meant that national forestry agencies are under-funded, under-staffed, and are being split and downgraded in all the countries of the subregion. Additionally, in most countries, communities that live in or near forests and that are dependent on forests for their livelihoods and a stable environment, have very little political influence.

The demand for wood products will rise steadily as economic growth proceeds in the region, and sector is undoubtedly important for environmental protection with the increasing number of hydropower dams and greater risk of climatic extremes, but strategic plans for the sector need to set out clearly how these demands will be met and how much investment is needed. The days of muddling along must end.

1. Introduction

The forests of the Greater Mekong Subregion (GMS) are simultaneously among the richest forests in the world for biodiversity and among the most threatened with destruction. Newby (2009) reported that 1,068 new species had been discovered in the subregion during the previous decade. During the same period, according to the FAO Forest Resource Assessment for 2010, an estimated almost 6 million hectares (ha) of forest were lost in the GMS countries, excluding the People's Republic of China (PRC).

This richness in biodiversity is considered to be a result of the climate changes that took place during the last ice age, when sea levels were lower and tropical forest species were able to migrate and survive in the land that is now covered by sea between Thailand, Malaysia, and Indonesia, while more temperate forest species invaded the cooler mountainous areas. As the climate warmed, the tropical forest with all its associated biodiversity recolonized most of what is now the GMS. The recent more rapid phase in climate change attributed to human activities is also reported to be affecting the ecology of the subregion and Newby reported that changes in the frequency of storms and periods of drought combined with rising temperatures and melting of glaciers in the Himalayas, are all affecting the ecology of the subregion as well as agricultural productivity.

At the opening of the 20th century, forests covered about three quarters of the land surface of Thailand (McKinnon, 1997) and it is reasonable to assume that they covered a similar proportion of the lower Mekong Basin, in Cambodia, the Lao People's Democratic Republic (Lao PDR), and parts of the central highlands of Viet Nam. The vast majority of the population lived in the Mekong, Chao Phaya, and Red River deltas and coastal plains and practiced irrigated agriculture, while a minority of "hill tribes" lived in small scattered communities in the hill areas and practiced mainly shifting cultivation.

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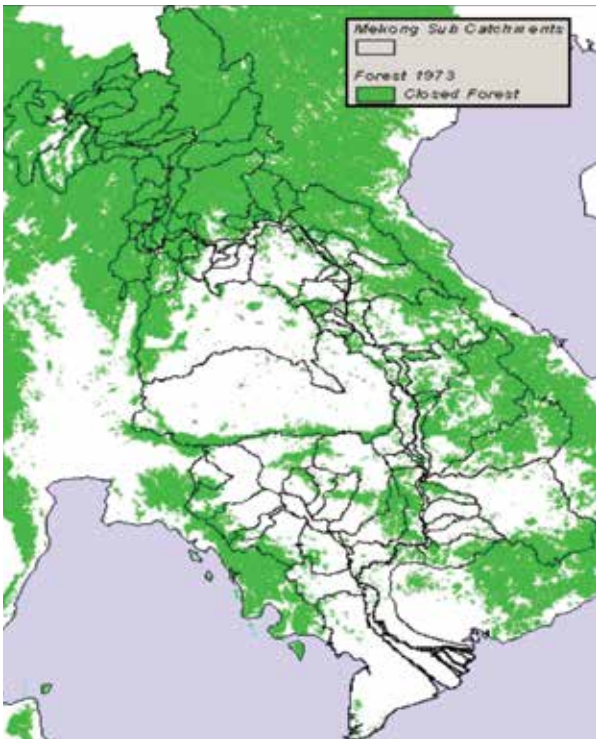
The climax forest type over most of the Mekong basin is semi-deciduous or deciduous monsoon forest as a result of the seasonal characteristic of the rainfall and the pronounced dry season. In the southern part of the basin to the south of about 10°, which is considered to be more or less the boundary between the evergreen and monsoon forest types, the climax forest is evergreen rainforest. To the north of this boundary a mosaic of evergreen and deciduous forest may be found where local climate, drainage, and soil conditions result in moister conditions and favor the development of evergreen species. The species composition of these two major forest types is different, and further local differences may occur at higher latitudes, higher altitudes and in riparian, wetland and coastal forests.

The first comprehensive survey of forest cover for the lower Mekong Basin in 1973 suggested that forest cover had been reduced to about 55% over the basin as a whole, with an estimated forested area of about 34.5 million ha within the basin area of 62.5 million ha.

Figures 1 and 2 show the distribution of forest cover in the lower Mekong Basin in 1973 and 1997, respectively. Over the 24 years from 1973 to 1997, almost 16 million ha of forest were lost, averaging 660,000 ha annually or about 2% of the forest area and reducing forest cover to around 30% by 1997.

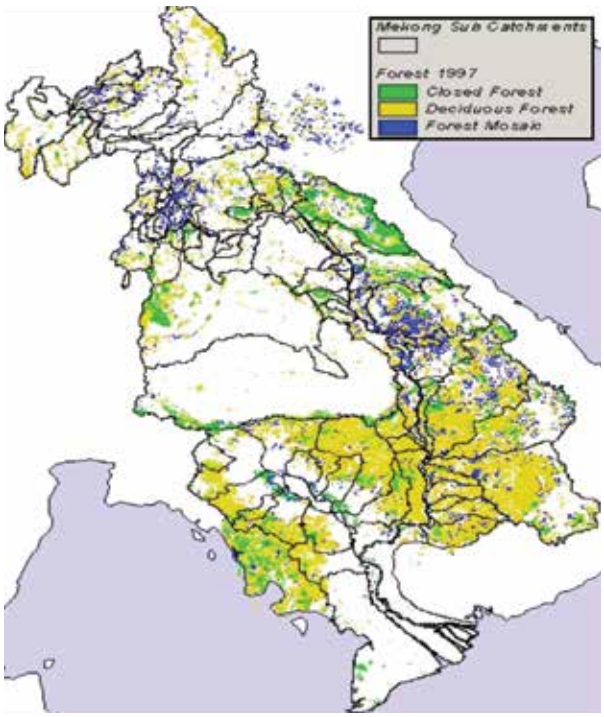
Examination of the distribution of forest cover by Fraser and Jewell (2003) according to slope classes in 1973 and the subsequent deforestation revealed that deforestation was relatively higher on the steeper slopes than on the flatter land. Of the 16 million ha of forest that were lost during 1973–1997 almost 25% appears to have been on slopes steeper than 21%, although this slope class only accounts for about 11% of the total area of the basin. Table 1 gives a summary of the apparent loss of forest cover during the intervals between the surveys on each of the slope classes. Table 2 gives the apparent annual loss of forest cover by slope class during the periods between the surveys, expressed as a percentage of the forest area at the beginning of the period.

Figure 1: Closed Forest (1973) from Landsat Multispectral Scanner Data



Source: Data from Tropical Rain Forest Information Center, Michigan State University.

Figure 2: 1997; Closed, (green) and Open Forest (brown) and Forest Mosaic



Source: Mekong River Commission.

Table 1: Change in Forest Area 1973–1997 by Slope Class in the Lower Mekong Basin

Slope class	Forest Area ('000 ha)				
	1973	1985	1993	1997	Loss 73-97
Steep	6,459.9	11,085.1	3,560.5	2,679.5	3,780.4
Intermediate	24,051.3	17,047.9	14,901.2	12,520.9	11,530.4
Gentle	4,030.4	3,600.0	3,990.8	3,494.9	535.4
Total	**34,541.6**	**31,733.0**	**22,452.6**	**18,695.4**	**15,846.2**

Source: Fraser and Jewell (2003).

Table 2: Average Annual Rate of Change of Forest Cover 1973-1997 by Slope Class in the Lower Mekong Basin

Slope class	Rate of Change in Forest area (%)				
	1973–1985	1985–1993	1993–1997	1973–1993	1973–1997
Steep	0.28	6.83	5.32	2.81	2.73
Intermediate	0.44	5.44	5.29	2.32	2.41
Gentle	0.92	1.45	3.66	1.07	1.37
Total	**0.68**	**3.66**	**4.18**	**1.75**	**1.91**

Source: Fraser and Jewell (2003).

Table 3: Total Annual Deforestation ('000 ha) in five GMS Countries, 1981–1990

Countries	Deforestation (annual)	Evergreen	Moist Deciduous	Dry Deciduous	Hill and Montane	Logged
Cambodia	131.4	18.3	39.0	73.2	1.0	3
Lao PDR	129.4	39.6	42.7	20.6	26.5	9
Myanmar	400.6	161.6	169.7	4.2	46.3	198
Thailand	515.3	150.8	195.8	122.3	17.9	37
Viet Nam	137.0	47.7	55.7	15.7		58
Total	**1,313.7**	**418.0**	**502.9**	**236.0**	**91.7**	**305**

Source: FAO Forest Resource Assessment for 2010.

This relatively high loss of forest cover on moderate and steeply sloping land has implications not just for the forest resources but also for water and soil conservation and the likely impact of the reduced forest cover on the potable water, irrigation, and hydropower utilities.

Table 3 uses FAO data covering the whole of five countries in the GMS, with a total area of about 190 million ha and a forest area of about 77 million ha or about 40.5% in 2000. The total area of these countries is almost three times larger than the lower Mekong Basin referred to above. Table 3 shows that during 1993 to 1997, about 1.3 million ha of forest were lost annually throughout the 5 countries, representing an annual loss of about 1.4%. The rate of loss of forest cover appears, therefore, to have been substantially higher in that part of GMS that lies within the lower Mekong Basin than in the GMS as a whole.

As a consequence of this rapid decline in forest resources, most countries in the subregion have imposed logging bans and the measured contribution of the sector to national gross domestic product (GDP) has declined steadily. These indicators, however, do not take account of the impact on national GDP of the reduction in the value of the ecosystem services provided by forests or the economic costs to communities living in forested areas that have lost access to nontimber forest products, on which many communities rely heavily.

2. Declining Performance of the Forest Sector

A forest policy paper for ADB in 2001 indicated that the main constraints that contributed to the under-performance of the sector prior to that time were:

- uncertainties relating to land tenure and "ownership" of the resource;
- misguided or inefficient pricing policies relating to forest products and competing sectors, especially agriculture;
- lack of assessment of the economic value of forests and the costs of environmental degradation; and
- low political priority to forestry and national institutional weakness in implementation of policy and projects.

Based on this assessment, appropriate interventions in the forestry sector were identified that would simultaneously address the sector's needs for development and poverty reduction:

- Land issues, covering the appropriate valuation of land under different uses, the assessment of economic rent and the most appropriate ways for governments to capture the rent.
- Market issues, covering both pricing policies that avoid distortions, and mechanisms for creating a market for forest goods and services that will stimulate greater private sector involvement in the sector.
- Employment issues, covering both the creation of additional off-farm employment opportunities, in particular for women, and the appropriate valuation of labor inputs.
- Environmental issues, covering both the proper valuation of the costs of environmental degradation, and the benefits of environmental services provided by forests.
- Governance issues, covering institutional capacity to undertake economic evaluation of forestry activities, identify the appropriate instruments to use in support of policy, and reduce intersectoral conflicts, particularly those arising from market failures; and eliminating corruption.

Mir and Chandrasekharan (2006) examined the economic cost of the destruction of the forest resources of the GMS and also took account of the impact of the steady degradation of the remaining forest that does not show up in crude measures of forest area changes. Their conclusion was that between $27–54 billion of capital value in the forest was being destroyed annually. This only took account of the apparent loss in growing stock with a timber or fuel market value that could not be accounted for by official records of timber harvested and took no account of the value of soil lost due to erosion in forest that had been cleared on steep slopes, or any contribution to flooding and river siltation that may also be attributed to reduction in forest cover. Mir and Fraser (2003) in their study of illegal logging in the subregion pointed out that the officially recorded annual harvest of industrial logs in 2000 for the countries of the Asia-Pacific region was 283 million cubic meters (m^3) while the volume of wood required to produce the recorded volumes of all products was 440 million m^3. Imports from outside the region accounted for about 55 million m^3 of the difference, but there was still a discrepancy of around 100 million m^3 that was unrecorded and probably illegal.

While these figures are for the wider Asia-Pacific region there have been numerous studies of illegal logging and trade of logs within the GMS. Meyfroidt and Lambin (2009) examined the apparent log supply deficit in Viet Nam. They concluded that in 2006, the deficit in logs in Viet Nam was around 10 million m^3, most of which was being met by illegal log imports from neighboring countries. Had these logs been harvested from Vietnamese forests they would have suffered substantial deforestation and reversed the trend in increasing forest cover shown by Vietnamese statistics as a result of expansion of plantations. Instead the deforestation was displaced to neighboring countries. Since no royalty or fee is paid on illegal logs, this represents a substantial financial loss to the governments of the countries from which the logs are taken as well as a longer-term impact on the growth of the forest due to the reduced growing stock (capital).

3. The Current Status of the Forestry Sector in the GMS

A regional study undertaken by ADB in 2006 on Poverty Reduction in Upland Communities in the Mekong Region through Improved Community and Industrial Forestry showed that the forestry sector provides investment opportunities that can greatly contribute to poverty reduction through the creation of employment and increase off-farm income-earning possibilities, improved rural infrastructure, provision of renewable energy in convenient forms, sequestration of carbon, provision of a resource for small and medium-size enterprises, protection of the environment and the landscape, health care support through the supply of natural drugs, and the promotion of the well-being of women and minorities in rural areas through sound planning of the above activities.

Realizing these opportunities is not dependent on an existing forest resource, since the demand for forest products and services is strong, even in countries with little or no natural forest, and can be largely met by establishing plantations. The analysis also showed that risks associated with investments in forestry include normal commercial risks, such as fire and disease that can be assessed and minimized and serious governance and political risks that are much more difficult to handle. These risks will need to be minimized in the future if investment in the sector is to be attractive and to be economically efficient, with possible beneficial impact on poverty reduction.

Sustainable forest management will require a stable resource base and countries need to have land-use plans that determine as far as possible, the balance between the alternative uses that brings the greatest overall benefit. Forests should only be converted to another use where

it can be demonstrated that that the total net benefits from the alternative will exceed the loss of benefits from the forest that is converted. Under-valuation of forest resources promotes wasteful use, illegal logging, and corruption, and results in reduced government revenue. Illegal logging is a symptom of a lack of appreciation of the resource, and if it is allowed to persist it will undermine the benefits of any further investment in the sector.

Successful investment in forestry requires good management, and national forestry agencies are not organized for management. The role of government should be to ensure a sound regulatory framework, with the use of appropriate fiscal and other financial incentives and to enforce compliance. The latter requires more monitoring effort. Low political priority for forestry has generally meant that national forestry agencies are under-funded, under-staffed, and have very low status within government. These shortcomings show up as a general lack of any clear prioritized and realistic strategic objectives related to the available investment funds for the sector and lack of any appreciation of its economic value.

The future for the sector does not look bright as forestry departments are being split and downgraded in all the countries of the subregion, so that responsibility for forest management is split between agencies according to the primary function of the forest. In fact, all forests have multiple functions, although within a forest management unit, different functions (conservation, protection, production) may be given priority in specific areas. In all countries, the responsibility for the resource is separated from the responsibility for the subsequent processing of the wood and coordination is generally very poor, with the result that the industry agency may be pushing to expand wood processing while the resource is being depleted. This leads, among other things, to a temptation to the industry to engage in illegal logging

In most countries, communities that live in or near forests and that are dependent on forests for their livelihoods and a stable environment, have very little political influence. The priority attributed to forestry is, therefore, generally low except where influential people have a direct stake in forestry activities. This low priority is, however, not always justified in economic terms on the basis of the full contribution that the whole forestry sector is making to the national economy.

The demand for wood products will rise steadily as economic growth proceeds in the subregion, and sector is undoubtedly important for environmental protection with the increasing number of hydropower dams and greater risk of climatic extremes, but strategic plans for the sector need to set out clearly how these demands will be met and how much investment is needed. The days of muddling along must end.

4. What Hope for the Future for GMS Forests?

The growing international attention to climate change may bring a respite to the steady decline in the fortunes of forestry sectors around the subregion. With most of the valuable timber already logged in areas designated for production, attention has turned to the conservation and protection functions of forests, and this has been helped by the realization that forests are both a source of carbon dioxide (CO_2) emissions contributing to global warming and also a sink for it, if trees are able to grow. The steady deforestation and forest degradation in the past throughout much of the subregion has resulted in high levels of CO_2 emissions, which are generally declining due to lower carbon stocks in the remaining forests when cleared. Despite this, and the relatively low current market value for CO_2, protecting what forest that is left and restoring forest cover wherever multiple benefits can be obtained, to include soil, water, biodiversity, and carbon, are becoming economically attractive. Many donors are now supporting forest protection and conservation and the international negotiations on REDD+ have opened the door to the possibility of substantial funding for such activities.

Since a high proportion of the poverty in the subregion is in the more remote and often upland areas where forests still survive, these opportunities need to be used to involve these rural communities and ensure that they receive a substantial share of the benefits in order to overcome their poverty. At the same time, there needs to be a realization among political leaders that the days of vested interests making money out of illegal logging must finish. Access to REDD+ funds will be severely hampered if changes in carbon stocks cannot be accounted for. This applies not only to forests within countries, but also cross-border leakage, which will jeopardize efforts by the countries that are being exploited. There is evidence to show that if log harvesting is carried out well, with proper attention to pre-planning of access, directional felling, and careful extraction, emissions of CO_2 resulting from the collateral damage to remaining trees can be greatly reduced. Illegal logging, which pays no attention to these matters, results in far higher emissions and has the added negative impact

that young regenerating trees are damaged and often killed and the future health and growth of the forest is compromised.

There is much emphasis in forest policies and strategies around the subregion on achieving a specified percentage of forest cover. However, plans for restoring forest cover depend mainly on plantations. Restoring natural forest areas by natural regeneration or enrichment planting with a wide range of indigenous tree species will contribute to the conservation and even enhancement of biodiversity, but plantations of exotic species such as *Eucalyptus* and *Acacia* should be treated along with rubber as commercial tree crops.

It would be better if forest strategies focused more on protecting and managing a more limited area of forest where multiple benefits are derived. These should include peri-urban, coastal, and riverine forests that protect the environment and provide good opportunities for recreation and tourism as well as upland forests that provide biodiversity, soil, and water conservation benefits. Industrial timber plantations provide a longer-term and more sustainable means of supplying timber needs and strategies need to base the areas to be planted on estimates of future demand to be supplied from national sources and imports (from legal and sustainable sources) as appropriate. The natural forests in the subregion contain mainly hardwoods and many of the species are highly prized for decorative purposes. Strategies should aim to conserve stocks of these valuable species and use them to maximum value and build resources of plantation species for utility purposes, such as construction and joinery, where the decorative properties are not required.

Modern furniture makes increasing use of medium-density fibreboard, which can be enhanced by facing with a veneer of the valuable species, and forest and wood industry development strategies need to be synchronized so that demand and supply are as closely balanced as possible. This will help to reduce the pressure to log illegally. Forest strategies need to be far more specific and realistic and should prioritize what needs to be done according to the resources, both human and financial, that are available. This will ensure that the strategies can actually be implemented rather than being a shopping list of things it would be nice to do.

Fraser (2001) pointed out that for forestry strategies to work there needs to be an understanding of what the strategy is trying to achieve, general agreement on the approach and measures to be adopted, and full support for it by all, with a vision of how forests will contribute to the well-being of the population in the future. There also needs to be clear specification of the various legal and financial instruments that will be used to implement the strategy as well as the human resources. The human resources need capacity building, which takes time and costs money; what is achievable will depend on the time frame for building the necessary capacity.

These implementation measures are generally lacking from forest strategies. There seems to be a trend to fragment responsibility for forestry matters in the subregion, with the wood industry being under Industry, forest conservation under Natural Resources and Environment and general forestry under Agriculture. This makes it extremely difficult, or even impossible to develop and implement a coherent strategy that would enable the sector to make its proper contribution to the economy. Foresters need to assert themselves more and find political champions who will press the case for reforms, and especially to face up to the threat from illegal logging.

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USING SPATIAL MODELS TO IMPROVE THE OUTCOMES OF LAND-USE PLANNING: THE CASE OF QUANG NAM PROVINCE, VIET NAM

Lothar Linde[1] and Wilbert van Rooij[2]

Abstract

Land-use planning has to carefully balance increasing pressures from development with the coping capacity of underlying natural resources and systems. A decline in the abundance, quality, and resilience of natural resources does not only affect the environment itself, but also sectors that heavily depend on intact ecosystem services, such as hydropower and ecotourism.

To better account for these conflicts as early as possible in sector planning and facilitate the identification of sustainable alternatives, the Quang Nam Province Department of Natural Resources and Environment commissioned a Strategic Environmental Assessment of their Provincial Land Use Plan 2011-2020. Support on scenario development and evaluation of corresponding impacts was provided by the Greater Mekong Subregion Environment Operations Center and the Netherlands Environmental Assessment Agency. Two scenario-based geographic models played a critical role in improving depth and detail of this assessment: The CLUE-s land demand allocation model previewed the risks of land conversion in hydropower catchments, and the GLOBIO3 biodiversity pressure model identified potential future biodiversity loss in important ecotourism sites.

1. Introduction

The Economic Corridor Concept is the main instrument of the Asian Development Bank (ADB) to close the gap between urban and rural disparities in the Greater Mekong Subregion (GMS). Transboundary roads between major economic centers are aligned through remote and impoverished areas to establish connectivity to markets. This is followed by corridor and sector plans laying out options for local investments. Together, road development and attached investment plans create an economic corridor that provides new livelihood opportunities for previously marginalized population. Currently, there are 3 main corridors: The North-South Economic Corridor (NSEC) linking Bangkok, Kunming, Hanoi, and Nanning; the East-West Economic Corridor (EWEC) linking Da Nang to Yangon, crossing the Lao People's Democratic Republic (Lao PDR) and Thailand; and the Southern Economic Corridor (SEC) linking Bangkok, Phnom Penh, and Ho Chi Minh City.

All three corridors pass through remote areas: the NSEC through the Golden Quadrangle, the EWEC through the central Annamite mountains, and the SEC through the Cardamom Mountains and Northern / Easter Plains Dry Forest. Catalyzing development in such socially and environmentally sensitive areas comes with impacts that might—if not managed carefully—outweigh the benefits for the local people. Recognizing that GMS governments need support to ensure sound investment planning along the corridors, ADB spearheaded the integration of geographic information systems (GIS) into strategic environmental assessments (SEAs) of sector strategies and plans.

Developing baseline maps is an important first step to leverage the potential of a GIS for sector and land-use planning and related SEAs. Planners and decision makers can use such thematic maps to (i) better understand the environmental, social, and economic condition of a landscape, and (ii) identify where different landscape components form synergies or conflict each other.

The potential of GIS, however, goes far beyond the production of basic thematic maps. GIS can further be used to develop predictive models that combine geographic layers with expert knowledge on safeguards, past trends, and future scenarios. Such models can generate maps that preview the geographic outcomes of different development pathways, quantify related impacts, and help identify sustainable alternatives. This GIS functionality blends well with the analytical requirements underlying most strategic sector plans.[3]

The usefulness of GIS models for environmental assessments and performance monitoring was demonstrated in several publications and pilot projects. Since 2004, the GLOBIO3 biodiversity pressure model has been extensively used in global environmental reporting (e.g., United Nations Environment Programme

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[3] In particular, demand projections and (alternative) scenario development components.

[UNEP] Global Environmental Outlook [GEO3], United Nations Convention on Biological Diversity [CBD] Global Biodiversity Outlook [GBO2,3]). The GLOBIO3 framework has also been implemented as part of subregional Monitoring and Evaluation (M&E) frameworks, among them the ADB-UNEP Subregional Environmental Performance Assessment Report. In the GMS, the Netherlands Environmental Assessment Agency (PBL) also supported the development of national biodiversity pressure maps in Viet Nam through a collaboration and training program with the Ministry of Planning and Investment.

Most of these applications, however, focus on the post-evaluative part of the planning process (i.e. monitoring and evaluation). While that has successfully raised broader awareness of the impacts of past development, it has had limited influence on ex-ante decision making, namely sector strategies and plans. In the GMS, the Environment Operations Center (ADB Regional Technical Assistance [RETA] 6289) has applied the CLUE-s land demand and GLOBIO3 biodiversity pressure models to improve scenario development and impact assessment of the SEAs of the NSEC Strategy and Action Plan. Apart from that, GIS models remain underutilized in GMS ex-ante planning processes, losing out on important opportunities to improve decision making and avoid or mitigate costly impacts.

2. At the Gate of the EWEC: Viet Nam's Quang Nam Province

Viet Nam's Quang Nam Province is in unique geographic position: Together with TT Hue Province, it encloses the city of Da Nang, Central Viet Nam's largest business hub and the country's third largest economic center. Da Nang has also established itself as a node for international and regional trade through its sea port and the gate to the EWEC.

Quang Nam contributes to and benefits from Da Nang's industrial development, mainly through supplying important natural resources and services: agriculture and aquaculture outputs from the coastal plains in the east; and timber, minerals, and hydropower from the Annamite Mountains to the west. Particularly the latter, however, is environmentally sensitive and has a limited carrying capacity with regard to land conversion and resource extraction. This has already resulted in several conflicts. Increased soil erosion from upstream deforestation and mining activities threatens the performance of hydropower plants (maintenance, operational period) and their ability to contribute to energy security targets (Figure 1). Water contamination from mining operations in the upper watersheds has impacts on downstream fisheries, irrigation, and safety of potable water. A loss of attractiveness of eco- and ethno-tourism sites—like national parks and indigenous villages—is limiting the growth potential of the tourism sector (Table 1).

Besides the risks to individual sector performance, the people most vulnerable to the impacts are marginalized ethnic minorities living in the Annamite Mountains. Immigration into the area increases pressure on their ancestral land, compromises their traditional forest-

Figure 1: Land Conversion on Slopes, Sediment Load in Rivers, Ta Bhing commune, Quang Nam Province, Viet Nam

Table 1: Growth Trends in Quang Nam Province

Indicator	2000	2010	Increase
Population	1,395,297	1,425,395	2%
Agriculture - industrial plantation (rubber, coffee, tea) (ha)	3,528	8,312	136%
Agriculture - orchards (ha)	4,698	8,782	87%
Tourism - tourists (number of arrivals)	1,362,000	2,400,000	76%
Tourism - revenue (billion VND)	900	2,162	140%
Hydropower - number of dams	0	10	-
Hydropower - installed capacity (MW)	0	714	-
Hydropower - remaining potential (MW)	1,328	614	-

ha = hectare, MW = megawatt, VND = Vietnamese dong

based livelihoods, and exposes them to new health and disaster risks (e.g., communicable diseases, floods, and landslides), essentially moving them from one form of marginalization (lack of connectivity to markets) to another (displacement from their land and forest resources). Achieving poverty targets (national goals and Millennium Development Goals [MDGs]) might not be realistic if there is not enough consideration on how to properly assess and respond to impacts on their livelihoods with appropriate compensation and mitigation measures.

3. Applying Predictive Models in Quang Nam's land-use planning

To help the Department of Natural Resources and Environment (DONRE) of Quang Nam Province to better account for the increasing land and resource demand and its implications on sector, environment, and social performance, the Environment Operations Center supported a SEA of the Quang Nam Land Use Plan 2011–2020. Development of a land-use plan (LUP) started in February 2010 and concluded in December 2010 with the submission of the draft LUP to the Provincial People's Committee (PPC) for approval. The SEA ran parallel (ex-ante) to the land-use planning process (baseline assessment, scenario development, economic valuation, plan) and complemented each step with specific inputs:

1. Baseline assessment: preparation of thematic maps highlighting environmentally sensitive areas (steep slopes, protected areas) and investments (hydropower, ecotourism sites).
2. Scenario development: review of the "business as usual" scenario used by the LUP team, development of an alternative scenario.
3. Economic valuation: quantification of the potential risks of two scenarios to the performance of two main growth sectors—hydropower (catchment integrity) and ecotourism (site attractiveness).
4. Plan: recommendation on revisions of demand allocations and inclusion of safeguards and mitigation measures.

Two geographic models were piloted in steps 2 and 3 to identify potential conflicts between sector land demands and requirements (agriculture vs. hydropower and ecotourism) and facilitate a discussion on finding mutually beneficial alternatives. The models—a land demand allocation model for hydropower catchment integrity and a biodiversity pressure model for ecotourism site attractiveness—are introduced in the following sections.

3.1 CLUE-s Land Demand Allocation Model

3.1.1. Approach

The CLUE-s model – short for Conversion of Land-Use Change and its Effects – is a land demand allocation model developed by the Wageningen Agricultural University. The SEA team used CLUE-s to translate Quang Nam Province land demand scenarios into future deforestation maps in hydropower catchments. The CLUE-s modeling framework achieves this through the following inputs:

1. *Land demand scenarios*: Formulation of projected land demand in hectares, established from past land conversion trends (business as usual) and sector development targets (business as usual, sustainable alternatives).
2. *Conversion sequences*: Definition of how land-use types convert between each other, guided by economic values/prioritization.
3. *Land-use map*: A representation of the present distribution of land cover and land uses.
4. *Conversion restrictions*: Identification of areas that are restricted for future land conversion, such as protected areas or land concessions.
5. *Aggregated land suitability*: A set of underlying geographic layers (e.g., slope, soil type, distance to road, distance to settlement) with strong influence on the distribution of individual land uses.

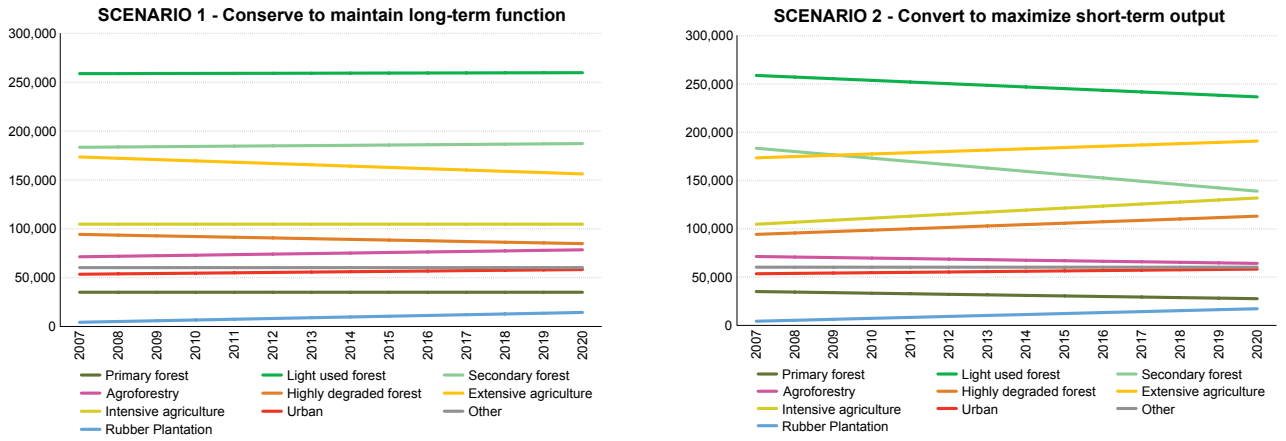
The modelling framework includes both nonspatial and spatial components. The nonspatial components (1, 2) are developed through consultation with decision makers and allow them to engage in and influence the outcomes of the modeling process. Based on this knowledge and spatial inputs (3, 4, 5), the land demand allocation procedure calculates future land-use maps for each scenario.

3.1.2 Scenario development

The nonspatial components of the model were developed in consultation with the LUP and SEA stakeholders in February and May 2010, with follow up literature review in November 2010. These inputs broadly defined past development trends and present sector demands, establishing the base for formulating 2 land demand scenarios (Figure 2).

Land Demand Scenario 1 – Conserve to maintain long-term function: This scenario puts emphasis on the conservation of environmental assets to secure performance and enhance potential of the tourism and energy (hydropower) sectors that rely on healthy ecosystems. Additional demand from the agriculture sector is met through productivity

Figure 2: Two Land Demand Scenarios used as Inputs in CLUE-s



enhancement measures rather than land expansion. Sustainable financing tools and mechanisms engage local communities, provide them with new sustainable livelihood opportunities, and provide other sector developments with incentives for "greening" their investment portfolios.

Land Demand Scenario 2 – Convert to maximize short-term output: This scenario focuses on timber harvesting and expanding commercial plantations to satisfy the increasing demand from the manufacturing sector (furniture, rubber, pulp and paper). This is combined with maximizing agricultural outputs through land conversion rather than productivity enhancement. Spatial restrictions—despite existing—are not enforced efficiently.

3.1.3 Spatial data inputs

In order to develop model results that closely align to the provincial land-use planning procedure, official government datasets and expert knowledge were used wherever possible. In case of the baseline land-use map, however, different government datasets showed different strength and weaknesses: MARD-FIPI forest data are accurate on forest cover but broad in terms of land uses, and MONRE data show appropriate detail for agricultural land uses but remain broad in forest areas. Therefore, to leverage the best of both and improve on the accuracy of the model outputs, the baseline land-use layer (2007) was collated from 3 sources: MARD/FIPI Forest Cover Classification of 2008 (for forest classes), MONRE Land Use Classification of 2005 (for land-use classes), and classification of AWIFS satellite imagery of 2007 (to fill gaps between the MARD/FIPI and MONRE datasets).

Following the development of the baseline land-use map, additional spatial components of the model were prepared. A layer of spatial policies and restrictions was generated from information on protected areas (special use forest, MONRE) and biodiversity conservation corridors (ADB CEP-BCI[4]). The land suitability component of the model was configured with eight "explanatory" layers: elevation, slope, aspect, cost-distance to coast, cost-distance to road, cost-distance to rivers, population density, and cost-distance to settlement.

3.2. GLOBIO 3 Biodiversity Pressure Model

The second predictive model, the GLOBIO3 biodiversity pressure model, was developed by a consortium consisting of the UNEP World Conservation Monitoring Centre, UNEP/GRID Arendal, and The Netherlands Environmental Assessment Agency (PBL). In the context of the SEA of the Quang Nam LUP 2011–2020, it was used to broadly assess the threat of biodiversity loss to the value of ecotourism assets (protected areas).

3.2.1 Approach

The GLOBIO3 model uses one of the indicators listed by the CBD (CBD, 2006): the mean species abundance (MSA), expressing the relative abundance of original species at present compared to their potential abundance in undisturbed ecosystems. This measure provides a good indication for the overall "naturalness" of an ecosystem and the "intactness" of embedded ecosystem services.

[4] http://www.gms-eoc.org

Unlike other biodiversity models, GLOBIO3 does not measure biodiversity directly, but translates the magnitude of past, present, and future human-made pressure into loss of biodiversity (Alkemade *et al.*, 2009). These losses are subsequently discounted from potential (undisturbed) biodiversity levels, resulting in a map of "remaining" biodiversity. Pressure factors considered in the model are land-use change, infrastructure and population, fragmentation, climate change, and atmospheric pollution—each expressing a unique cause-effect relationship with biodiversity. These individual cause-effect relationships are translated into biodiversity loss using conversion coefficients derived from the literature through meta-analysis for comparable ecosystems. For subnational application, the quality of these global figures can be improved using local datasets and expert knowledge.

There are several advantages to this approach. First, GLOBIO3 does not require time-consuming, large-scale biodiversity surveys but "reverse calculates" the CBD MSA indicator from more readily available information on biodiversity pressures. By describing the state of biodiversity through the degree of pressure it is exposed to, the model also blends in better with the impact assessment focus of SEAs and Environmental Impact Assessments. Furthermore, GLOBIOs integration into a GIS combines information on ecosystem quality (MSA indicator) with data on ecosystem quantity (extent), providing more comprehensive baseline figures for valuation exercises, environmental targets, and safeguards development.

3.2.2 Scenario development

The implementation of the GLOBIO3 model in the SEA of the Quang Nam LUP 2011–2020 was divided into two steps: calculation of MSA as of today (2007), and estimation of change in MSA (biodiversity loss) between 2007 and 2020 as result of development.

Compared to CLUE-s, which uses a scenario to project thematic information (land use) into the same thematic information in the future, GLOBIO3 only translates thematic information (e.g., land use) into another measure (biodiversity pressure from land use). As such, GLOBIO3 does not have a scenario development component itself but builds on the outputs of scenario-based models (e.g., CLUE-s land-use maps of 2020). Pressure from future infrastructure and population was accommodated by increasing the road buffer width and assuming a population growth rate of 1% per year.

3.2.3 Spatial data inputs

The World Wide Fund for Nature (WWF) map of terrestrial ecoregions[5] was used as a reference to identify the mean species abundance without human interference. For the calculation of biodiversity loss by 2020, future land-use maps (CLUE-s outputs) were used as input for the land conversion and fragmentation components. Two more layers already used in the CLUE-s model are the provincial road layer (DONRE, 1:50.000) and the gridded population density (LandScan 2009); for GLOBIO3, they were used to calculate pressure from infrastructure and population development. Climate change and nitrogen deposition pressures components were not included because data of sufficient resolution were not available, supported by the fact that these pressures are unlikely to be significant over the plan period.

4. Results

The CLUE-s model produced two land-use maps: one of land use in 2020 following scenario 1 (Conserve to maintain long-term function) and one of land use in 2020 following scenario 2 (Convert to maximize short-term output) (Figure 3). A third map was produced combining both CLUE-s outputs for 2020 with the baseline map of 2007, showing (i) which areas change in both scenarios, (ii) which areas change in either scenario, and (iii) which areas do not change, regardless of scenario. These areas were highlighted in a land conversion map (Figure 5).

Corresponding to the land demand scenarios, the GLOBIO3 model produced two MSA (= biodiversity loss) maps: one for 2020 following scenario 1 (conserve to retain function) and the other of land use in 2020 following scenario 2 (convert to maximize output) (Figure 4). As a reference, an MSA map of 2007 (biodiversity loss as of 2007) was produced (Figure 6). Similar to the CLUE-s implementation, the difference between MSA in 2007 and 2020 was calculated for both scenarios and visualized in two corresponding maps (Figure 7).

[5] http://www.worldwildlife.org/science/ecoregions/item1267.html

Figure 3: Output of the CLUE-s Model: Future Land-Use Maps of Quang Nam Province (2020)

scenario 1 **scenario 2**

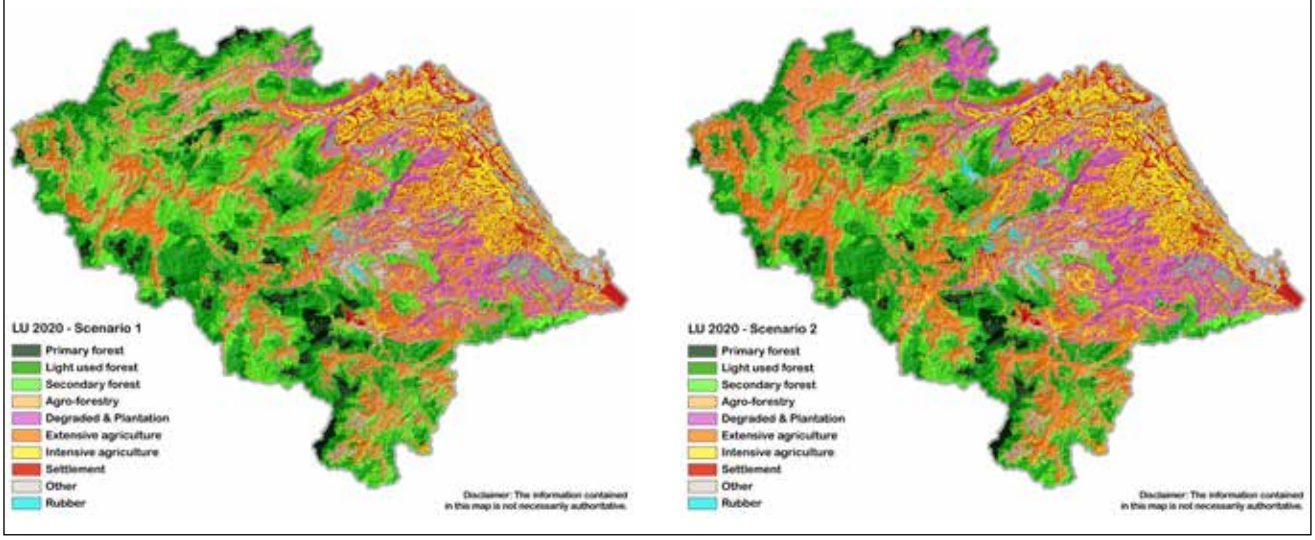
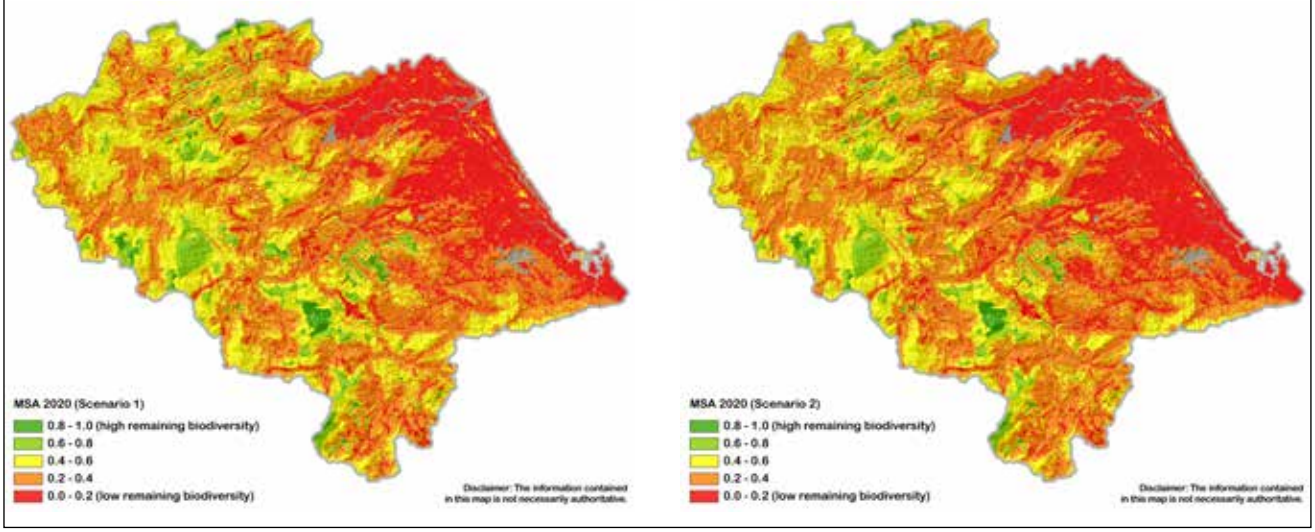


Figure 4: Outputs of the GLOBIO3 Model: Mean Species Abundance (MSA) of Quang Nam Province (2020)

scenario 1 **scenario 2**



5. Analysis

5.1. CLUE-s: Deforestation in Hydropower Catchments

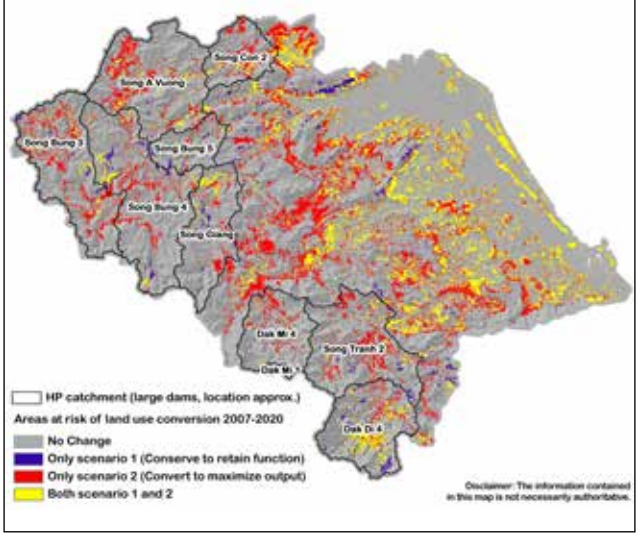
The CLUE-s outputs show similar land-use conversion patterns in the coastal lowlands for both land demand scenarios (Figure 5). Toward the Annamite Mountains, the differences between the scenarios become apparent: At the fringe between the coastal lowlands and the upland areas, conversion rates of scenario 1 reduce significantly, while scenario 2 maintains high conversion rates, even with a tendency to larger patch sizes compared to the lowlands. Land-use conversion trajectories generally align to mountain valleys, reaching even remote areas near the Laotian border.

Overlaying the catchments of major hydropower dams in Quang Nam on the land conversion map (Figure 5) puts the risk of deforestation into direct context with the

needs of hydropower investments for intact watersheds. Depending on the scenario and hydropower catchment, 4%–18% of the land is at risk of being converted (Table 2). The average conversion rate under scenario 1 is 5%, significantly lower than for scenario 2 (12%). Also, while in scenario 1 only one catchment (Dak Mi 4) faces the risk of more than 10% deforestation until 2020, scenario 2 has 7 hydropower catchments facing the same risk. The land demand allocation model also reveals that some dams are expected to be less affected by different development scenarios than others: while Song Bung 5, Dak Mi 1 and Dak Mi 4 show almost equal levels of risk of forestation in both scenarios, other dams show that a careful choice of development scenarios can result in significantly reduced risk of land conversion in hydropower catchments (e.g., Song Con 2: scenario 1: 5%, scenario 2: 18%; Song A Vuong: scenario 1: 4%, scenario 2: 15%).

Using these results as inputs into subsequent models, such as the Universal Soil Loss Equation can provide even more detailed figures for cost-benefit analyses and provide further important arguments for forest protection and development of ecosystem service payment trials in selected hydropower catchments.

Figure 5: Land Conversion Map overlaying the Spatial Impacts of Scenario 1 and 2 overlaid on major Hydropower catchments.



5.2. GLOBIO3: Biodiversity Loss in Protected Areas

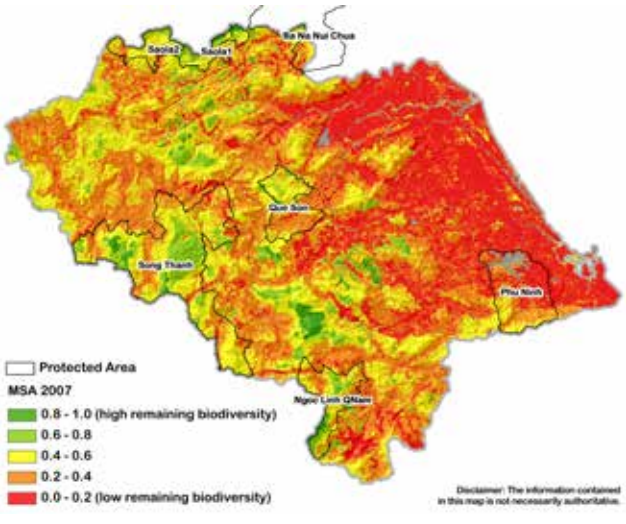
Starting with assessing the present levels of (remaining) biodiversity, Figure 6 suggests that in 2007 there were few pockets left where ecosystems were completely void of human influences and biodiversity was at or near pristine levels. Coastal lowlands have been almost entirely transformed into agricultural monocultures or settlements, and even small patches of forest might be plantations rather than natural forest. Corresponding to this, MSA values are generally low (<0.2 or 20%). Toward the mountainous areas, MSA levels generally remain higher, even though large valleys still do not show much more remaining biodiversity than coastal lowlands (20%–40%). Only very few areas—some mountain ridges—still show near-pristine biodiversity levels of 80%–100%. Overall, even in the mountains, most areas have biodiversity levels well below 60% of the pristine situation. That includes many areas labeled as "forest," suggesting that simply measuring the extent of forest is not a good proxy to make reliable judgments on ecosystem intactness and richness in biodiversity.

Calculating the difference between MSA maps of 2007 and 2020 provides the base for identifying which areas are expected to suffer from further biodiversity losses, and which areas are potentially relieved from pressures

Table 2: Risk of Land Conversion (Deforestation and Degradation) in major Hydropower Catchments of Quang Nam Province by 2020.

Dam	Total Area (ha)	Conversion Scenario 1 (ha)	Change (%)	Conversion Scenario 2 (ha)	Change (%)
Dak Di 4	45,919	6,285	14%	7,224	16%
Dak Mi 1	2,223	40	2%	28	1%
Dak Mi 4	34,217	677	2%	2,999	9%
Song Tranh 2	60,056	2,161	4%	7,697	13%
Song A Vuong	68,496	2,543	4%	10,059	15%
Song Bung 3	63,049	2,483	4%	9,281	15%
Song Bung 4	82,592	4,237	5%	8,103	10%
Song Bung 5	19,836	988	5%	1,229	6%
Song Con 2	24,099	1,197	5%	4,280	18%
Song Giang	41,462	2,411	6%	4,074	10%
Total	**441,949**	**23,022**	**5%**	**54,974**	**12%**

Figure 6: Mean Species Abundance of Quang Nam Province in 2007, overlaid on Protected Areas.



and even show signs of biodiversity recovery. Overlaying protected areas (PA)—the key assets for ecotourism—onto these maps reveals the different levels of impact of different development scenarios (Figure 7, Table 3). First, most PAs in Quang Nam have already incurred a significant decline in biodiversity: even though pockets of near pristine MSA exist in most of Quang Nam's PAs (>90% in Ngoc Linh, Que Son, Song Thang, and Sao La 1), the majority of the park areas were subject to significant levels of human intervention, resulting in area-weighted MSA values of 58% for Sao La 1 and as low as 29% for Phu Ninh.

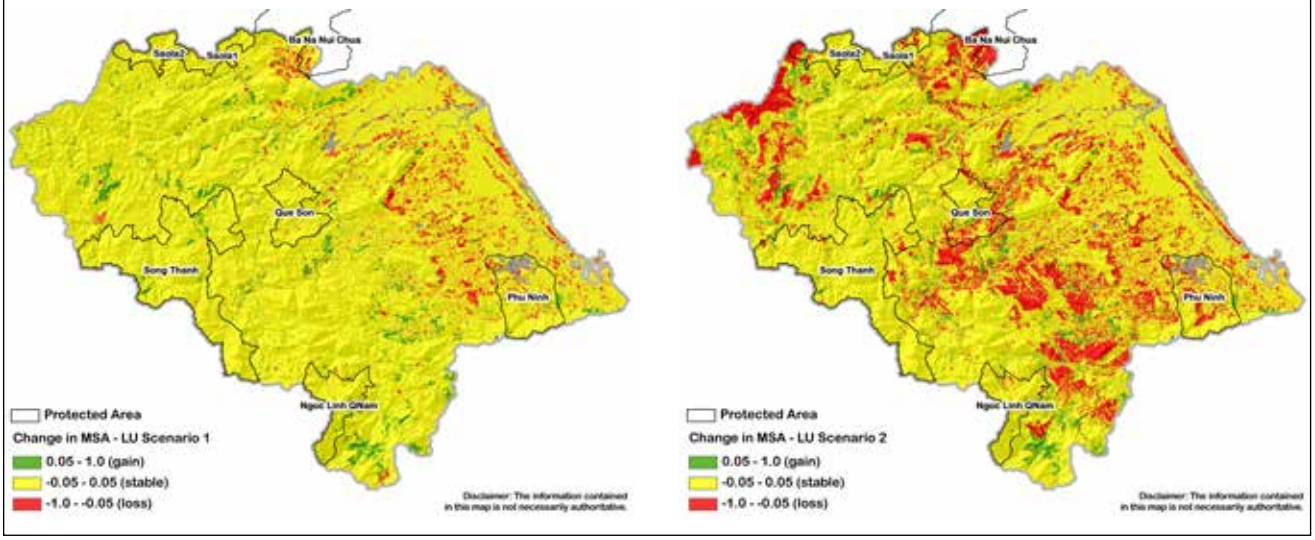
The additional impact of development differs by scenario: scenario 1 (conservation-oriented) keeps additional biodiversity loss well below 1% for all protected areas except Ba Na Nui Chua. In scenario 2 (convert to maximize output), biodiversity loss rates increase by factor of 3–5, with Que Son, Sao La 1, and Ba Na Nui Chua subject to potential biodiversity losses of 4.3%, 4.9%, and 11.7%, respectively, until 2020. Even if these biodiversity losses

Table 3: Risk of Biodiversity Loss in key Protected Areas of Quang Nam Province by 2020

Protected Area	Area (ha)	MSA 2007		MSA 2020 - Scenario 1				MSA 2020 - Scenario 2			
		Max	Mean	Max	Change	Mean	Change	Max	Change	Mean	Change
Ba Na Nui Chua (QN)	3,220	76%	36%	76%	-0.2%	33%	-3.7%	53%	-23.4%	25%	-11.7%
Ngoc Linh (QN)	19,114	95%	50%	95%	0.7%	49%	-0.3%	95%	0.0%	49%	-1.1%
Phu Ninh	27,965	87%	29%	87%	0.0%	29%	-0.5%	87%	0.0%	27%	-2.2%
Que Son	18,596	92%	42%	92%	-0.2%	42%	-0.5%	90%	-2.5%	38%	-4.3%
Sao La 1	8,005	96%	58%	96%	0.0%	57%	-0.9%	96%	-0.7%	53%	-4.9%
Sao La 2	9,881	65%	48%	64%	-0.2%	48%	-0.7%	64%	-0.7%	46%	-2.3%
Song Thanh	85,459	96%	49%	96%	0.0%	48%	-0.3%	96%	0.0%	48%	-0.9%

Figure 7: Areas of projected Loss or Gain in Mean Species Abundance until 2020.

scenario 1 **scenario 2**



still seem low over a period of 13 years (2007–2020), they have to be seen in context of the already low biodiversity levels in 2007. These seemingly low rates of biodiversity loss can cause 3 out of 7 of Quang Nam's PAs to drop below 25% of their remaining biodiversity by 2050, potentially depriving Quang Nam's tourism industry of its essential assets.

6. Outcome and Conclusion

The purpose of this pilot study was to raise awareness with national and regional planners on the relevance of GIS-based models in ex-ante planning. Selected models were introduced and their application demonstrated along a specific planning example, the Quang Nam Land Use Plan 2011–2020.

The exercise yielded several tangible outcomes. All relevant provincial stakeholders, the Department of Agriculture and Rural Development (DARD) and Department of Planning and Investment (DPI) as well as DONRE, were involved in scenario development. CLUE-s outputs highlighted the potential impacts of unrestricted agricultural land expansion on the integrity of hydropower catchments. Similarly, GLOBIO3 facilitated discussion on the conflicts between land expansion and the attractiveness of ecotourism assets. Outputs of both models proved to be powerful cross-sector communication tools, increasing the recognition of sector conflicts and understanding of the role of ecosystem intactness in sector performance (hydropower, tourism). As a result of this discussion, the LUP team revised the land allocation figures twice to better reflect these dependencies and harmonize sector requirements. Besides raising awareness with high-level planners and decision makers, the pilot project also built conceptual and technical capacity on CLUE-s and GLOBIO3 among DONRE, DARD, and DPI technical staff, creating the foundation for the successful application of these models in future provincial planning.

Despite these successes, several broader challenges remain. First, with no legal requirement for SEAs of provincial plans, commitment of provincial authorities to support SEA exercises with comprehensive scenario and impact assessment components remains limited. The LUP land allocation procedure is not transparent and appears to be demand driven (sector and national targets) rather than being based on a realistic assessment of the supply side, i.e., land suitability and coping capacity. Significant limitations with regard to GIS data availability and accuracy, particularly land cover and land-use data, make it difficult to turn this process around and develop reliable spatial information on sector-specific land suitability and budgeting of related supply. The result is that much of the land allocation used in land-use plans is actually coming out of commune-level statistical surveys rather than actual land-use maps, leading to significant inconsistencies between the plan and the associated land-use map. Viet Nam's rapid economic growth, sector diversification, and resource demands require significant investments in a national and provincial spatial data infrastructure that can cope with the resulting increased planning complexity.

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LAND, WATER, FORESTS, BIODIVERSITY, AND CLIMATE CHANGE IN MYANMAR

Htwe Nyo Nyo[1]

Abstract

Myanmar, a tropical coastal country, has a climate generally favorable for various agricultural practices, growth of forests, and development of fishing industries, all of which support the livelihood of majority of the population.

Climate change is likely to affect the agricultural economy. The projected increasing temperature and decreasing rainfall in central Myanmar may lead to the expansion of the country's dry zone, in which annual rainfall is less than 1,000 mm. In other areas, increasing heavy rain in the upper watersheds can increase the occurrence of flash floods, resulting in drowning of people and livestock and destroying infrastructure. Late monsoon onset will delay agricultural cycles, such as soil preparation for rice cultivation. This delay will disturb crop growth in the subsequent months, while abnormal weather may damage the crops. In the harvesting period, adverse climatic conditions can damage the ripening crop. Also, if climate-sensitive sectors, such as agriculture, livestock, and fisheries are largely disrupted by climate extremes, food security of rural communities could be impaired. Under such situations, they would have no alternative but to turn to the forests for intensified exploitation of wood and non-timber products for their survival and livelihood, and could finally destroy the forests.

Measures have been taken by the Government to develop agriculture. However, to reduce vulnerability to climate change, policies, legislation, and other supporting tools need to be developed by government agencies in a coordinated manner. This will help identify and implement adaptation strategies toward a peaceful modern country. For this purpose, institutional strengthening, technology innovation and transfer, provision of advanced tools and equipment, enabling condition with adequate funds, and collaboration with relevant national, regional, and international institutions and agencies are indispensable.

[1] Deputy Director, NCEA, Executive Member, Vision-Green Environment Myanmar (Vision-GEM).

1. Introduction

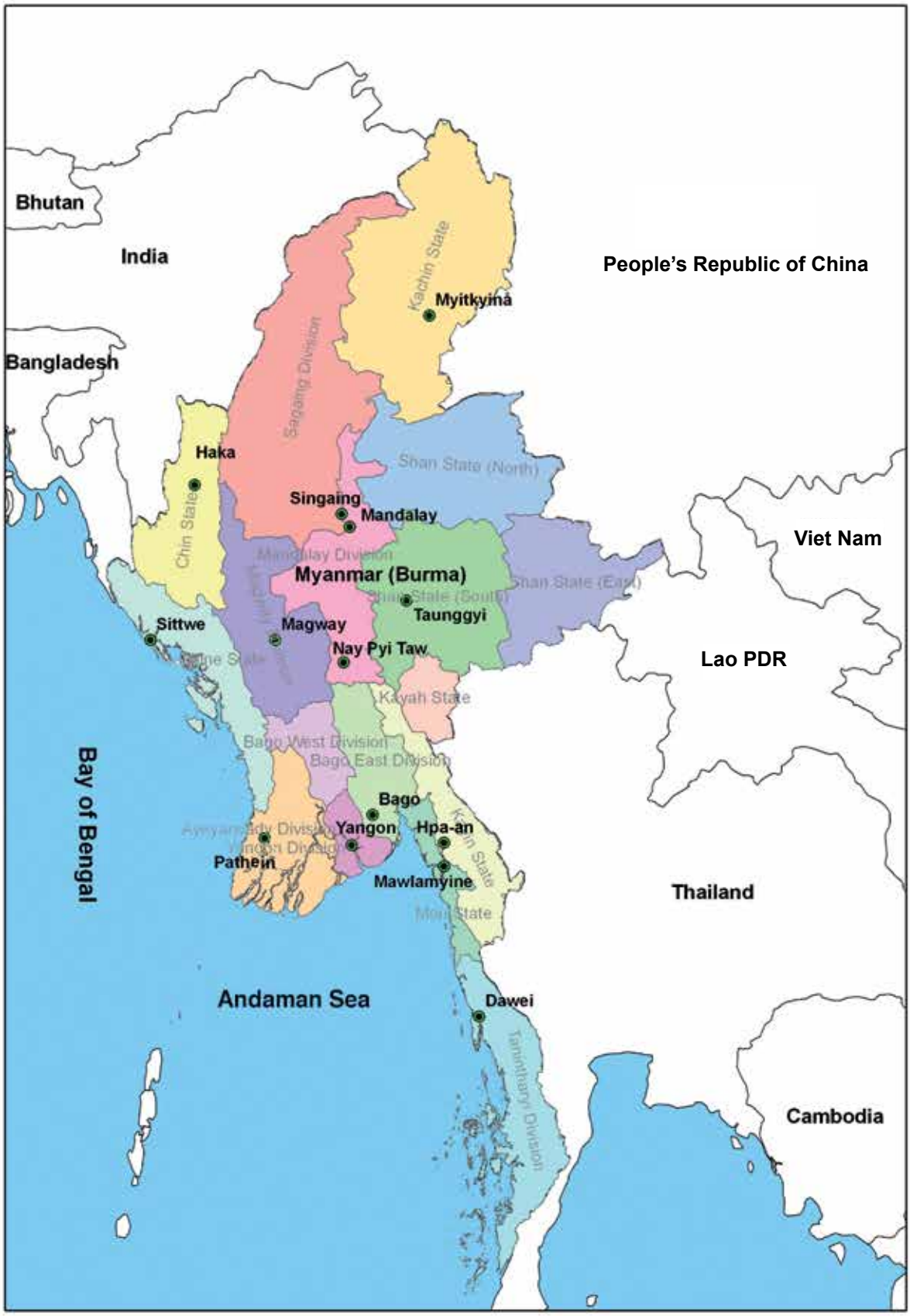
Myanmar is situated between latitudes 9º 53" and 28º 25" north and longitudes 92°10' and 101°10' east. Myanmar shares a border of 2,192 km with the People's Republic of China on the northeast, 224 km with the Lao People's Democratic Republic on the east, and 2,096 km with Thailand on the southeast. It also shares a 1,331 km border with India on the northwest and 256 km with Bangladesh on the west. Its 2,832 km coastline faces the Bay of Bengal in the west and the Andaman Sea in the south and southwest.

Myanmar has a land area of 676,577 km^2. The maximum width from east to west is 936 km and length from north to south, 2,051 km (including a 1,200 km long peninsula in the southeast) (Figure 1). Seven States and seven Divisions constitute the Union of Myanmar. The population in 2010 was estimated at 59.8 million, of whom some 67% are rural.

The climate is influenced by the tropical southwest and northeast monsoons. Myanmar has three distinct seasons: rainy, winter, and summer. During the rainy season, the weather is humid, wet, and warm, typical of the tropics. During the winter and the summer seasons, rain-showers occur occasionally.

The economy of Myanmar is currently in transition to a market-oriented structure. Efforts are being made to modernize and liberalize the economy on the basis of free enterprise and market mechanisms, with the provision of safety nets for vulnerable groups during the transition. Positive economic growth, as measured by gross domestic product (GDP), has been recorded in certain sectors of the economy. However, neither the rate of social decline and inequality nor the deterioration of natural resources usually associated with economic growth, has been satisfactorily studied or reported. With continued economic growth, challenges that face the country include macroeconomic instability, volatility of foreign exchange earnings, unstable exchange rates, low level of savings, large deficit, distortions in the price and incentive system, indiscriminate land use, and ecosystem instability. In 2010, the per capita GDP of Myanmar was only $702 (at current prices), according to International Monetary Fund estimates. However, because of its wealth in natural resources, Myanmar has great potential for economic development.

Figure 1: Map of Myanmar



2. Land, Water, Forest, and Biodiversity

2.1 Land Resources

The total area of 676,577 km^2 is divided into several land types as shown in Table 1. Forest covers about 49% of the total; the net sown area about 18% (including fallow land), and the cultivable waste land about 8%. The land area is divided into mountainous and plateau, plains, and river valleys. The mountain ranges and the plateau occupy the majority of the total area. The trend of expanding agriculture into forest lands can be seen clearly in the Ayeyarwady Delta, where agricultural fields and fish ponds are increasing among the forest in the northern part and mangroves in the coastal area.

Table 1: Area by Type of Land, 2009–2010

Type of land	Area (million ha)	% of total
Reserved forest	16.90	24.98
Other wood land	16.25	24.02
Current fallows	0.24	0.35
Net area sown	11.98	17.71
Cultivable waste other than fallows	5.61	8.29
Others	16.68	24.65
Total	**67.66**	**100.00**

Source: Ministry of Agriculture and Irrigation. 2011.

Forest areas are also divided according to types of vegetation, such as closed-broad-leaved, mangroves, bamboos, and conifers. Grasslands are few, intermingling with other vegetation. Alpine regions are found in the northwest, north, and northeast; coniferous forests occur along the eastern borders the northwest, north, and northeast; and coniferous forests are found along the eastern borders. Dry forest ecosystems generally dominate the arid and semi-arid regions, which make up about 20% of the land, especially in the central part of Myanmar where temperature is very high, rainfall is low, and the soils are generally deteriorating due to drought and desertification.

Shifting cultivation is practiced by about 2.6 million people living in hilly regions. It covers an area of about 142,000 hectares. Shifting cultivation is one of the main causes of deforestation, which in turn has led to soil erosion and land degradation. In the coastal and the delta region, waterlogging, flooding, and seawater encroachment are the principal causes of land degradation. Flooding and annual tidal water encroachment have caused soil salinization in these areas.

The topography of Myanmar can roughly be divided into three regions, the eastern hills, the central valley, and the western hills. There is extraordinary topographical diversity, with elevation ranging from sea level to nearly 6,000 m in the high mountain peaks in the north. The major mountain ranges are the Eastern Himalayan Range in the north; the Chin Hills in the west, extending northwards to southern India; the western plateau, between the Ayeyarwady River and the Bay of Bengal; the Bago Yoma located between the Ayeyarwady and the Thanlwin rivers; the eastern plateau located in the northeast of the country bordering with the PRC, the Lao PDR, and Thailand; and the Taninthayi mountain range located in the southern peninsula bordering Thailand.

2.2 Water Resources

Myanmar has eight river basins as shown in Table 2. The Mekong River flows along the border with the Lao PDR. According to 2003 data, the annual average potential amount of surface water is 828 km3 and groundwater 495 km^3 (Table 2).

Water withdrawals in Myanmar have been increasing, particularly in the agricultural sector. Table 3 shows total

Table 2: Annual Average Water Resources Potential, by River Basin

Name of Principal River Basin	Catchment Area ('000 km^2)	Average Annual Surface Water (km^3)	Estimated Groundwater Potential (km^3)
Chindwin River	115.30	227.920	57.578
Upper Ayeyarwady River (up to its confluence with Chindwin River)	193.30	141.293	92.599
Lower Ayeyarwady River (from confluence with Chindwin to its mouth)	95.60	85.800	153.249
Sittoung River	48.10	81.148	28.402
Rivers in Rakhine State	58.30	139.245	41.774
Rivers in Tanintharyi Division	40.60	130.927	39.278
Thanlwin River (from Myanmar boundary to its mouth)	158.00	257.918	74.779
Mekong River (within Myanmar territory)	28.60	17.634	7.054

Source: Ministry of Agriculture and Irrigation, 2011.

Table 3: Water Use (km³) in Different Sectors

Sector	Surface water	Groundwater	Total	Percent
Irrigation	40.69	0.81	41.5	91
Domestic	1.15	2.55	3.7	8
Industrial	0.32	0.08	0.4	1
Total	42.16	3.44	45.6	100

Source: Ministry of Agriculture and Irrigation. 2003. *Water Resources Management in Myanmar, 2003*.

water use in different sectors for the year 2004-2005 (Win, 2006). The agricultural sector is by far the largest water user. Previously, the government irrigation investment strategy was strongly oriented toward increasing the water supply by developing storage capacity, particularly by construction of dams, weirs, and sluice gates.

Wetlands, including big lakes and marshlands, also constitute a mechanism to regulate storage and flow of water in the country. Inle Lake, with its scenic beauty and traditional cultural attraction is shrinking due to soil erosion from the surrounding area because of forest depletion and degradation and unsustainable agricultural practices. Indawgyi Lake in Kachin State is also shrinking. Similar situations have occurred in many other places in Myanmar. Some tributaries of large rivers are contaminated with chemicals due to mining activities in their watersheds.

Groundwater is a major component of the available water resources. Groundwater, pumped manually and mechanically, provides additional water to villages that rely on ponds for harvesting rainwater during the rainy season.

Myanmar is rich in diverse inland aquatic ecosystems that contain an abundant fauna of freshwater fish and both resident and migratory birds, and aquatic plants. Inland waters and their biodiversity are a vital resource for the people in the country for agriculture, food, and transport as well as cultural and spiritual integrity.

Irrigation for agriculture has been developed, particularly in the dry zones, by pumping water directly from rivers and by drilling tube wells. Also, since 1990 to the end of 2010, the Irrigation Department has constructed 233 dams and reservoirs for irrigation and flood protection; about 1.68 million hectares of cropland are now irrigated, 17% of total sown area in 2009-2010.

2.3 Forest Resources

Forests are the most important of Myanmar's natural resources, not only for the livelihood of the people but also for the national economy as well. About half the total land area is covered by forests. There is a wide diversity of forest ecosystems. Forest types range from high alpine forests to coastal tidal forests (Table 4). Forest flora can be divided into 48 ecological subdivisions based on climatic, edaphic, and other factors. Among the principal categories, the mixed deciduous teak and hardwood forests and dipterocarp forests are the most important commercially. The mangrove forests in the coastal areas and Ayeyarwady Delta are vital for the ecological stability of these areas.

These diverse forests provide a wide range of goods and environmental services. Forty-five commercial timber species are extracted, with teak, ironwood, and rosewood being the most valuable and best known. The forests provide fuelwood to rural households and local cottage industries. Although the forestry sector accounted for only 0.54% of total GDP in 2006-2007, it generated about 10% of total export earnings, second only to the agriculture and petroleum sectors (CSO, 2008). Thus, the state of forest resources is of major significance for livelihoods and the economic stability of the nation. The areas under different forest types are presented in Table 4.

Non-timber resources include bamboo, rattan, bark, cosmetic *thanakha*, thatch, *indwe*, bat guano, pine, resin, bush meat, and parts of animals (hides, horns, bones,

Table 4: Major Forest Types

No.	Forest Types	Area (ha)	% of total forest area
1.	Tidal Forest	1,376,900	4
2.	Beach and Dune Forest		
3.	Swamp Forest		
4.	Tropical Evergreen Forest	5,507,800	16
5.	Mixed Deciduous Forest	13,425,300	39
6.	Dry Forest	3,442,400	10
7.	Deciduous Indaing (Dipterocarps)	1,721,200	5
8.	Hill and Temperate Evergreen Forest	8,950,100	26
	Total Forest Area	**34,423,700**	**100**

Source: Forest Department, Ministry of Forestry.

snout, hooves, fur, and tongues). Forest resources also include some 800 species of herbs, shrubs, and climbers, among which more than 300 are said to be potent and used as medicine. Many of these medicinal forest plants have been domesticated and are grown in nurseries and home gardens. Rural people still rely on these medicinal plants in times of illness and diseases.

Mangroves provide such products as charcoal, firewood, and housing materials; they also provide ecosystem services, such as feeding and spawning grounds for aquatic species, nesting places for wildlife, and protection against strong winds and seawater intrusion.

It is interesting to note the social attitudes toward forest conservation. In the dry zone of central Myanmar, agriculture is now at its upper limit and further horizontal expansion is almost impossible. The agricultural lands under private ownership are now being managed intensively and scientifically. Good practices have been spreading to other private lands under cultivation. Tree planting in private lands as well as in religious compounds is now a common practice in the dry zone. To reduce deforestation and forest degradation, cutting of trees for firewood has been prohibited in this zone by local authorities. Local people have solved the firewood shortage on their own. The groves of wild jujube (*Zizyphus jujube*) plants, which are now privately owned, are considered a gold mine.

The rate of deforestation increased and then declined over time, from a 2% annual loss between 1975 and 1989, 7% during 1989 to 1998, and 3.2% during 1998 to 2006, to 1.8% during 2006 to 2010 (FAO, 2010).

2.4 Biodiversity

Protection of soils, water, biodiversity, and the natural environment is identified as an important imperative in the 1995 Myanmar Forest Policy. Fauna and flora in Myanmar recorded to date are shown in Table 5. Flora include 273 plant families and 2,371 genera, of which 2,300 are trees, 97 bamboos, 26 rattan (cane), and 841 orchids. However, the market for wildlife and their parts is increasing in neighboring countries and the wildlife trade in Myanmar to meet the demand is growing, and has become a direct threat to wildlife. Unintentionally introduced invasive alien species further threaten the survival of native flora and fauna.

A protected areas system is well established, including parks and sanctuaries. Myanmar is committed to sustainable development of forests and biological resources through accession to a number of international conventions and agreements. The forestry sector is said to maintain a balance between environment, development, and social needs.

Table 5: Wildlife Fauna and Flora in Myanmar

No.	Description	Number of species
1.	Birds	1,056
2.	Mammals	251
3.	Reptiles	153
4.	Butterflies	1,200
5.	Plant species	7,000

Source: NCEA (1997, 2009c).

So far, 23 sanctuaries and 5 parks, constituting about 2.3% (15,270 km^2) of the total land area of the country, have been established. It is stipulated in the Myanmar Forest Policy that the coverage of the protected area system will be increased to 5% in the short term and 10% in the long term.

The Myeik Archipelago on the west coast, a beautiful island group comprising more than 800 islands with exposed peaks and several submerged ridges, has rarely been visited by humans, despite being in the geographical center of Asia. The archipelago offers a rare chance to see a natural environment almost untouched. Most of the archipelago's high islands retain forest cover dominated by tropical wet, evergreen forests in the interior and mangrove forests along the coast. The Myeik Archipelago is one of the few areas left on earth where there still exists a continuous transition from rain forest to coastal mangrove swamps.

The economy of Myanmar is largely based on the agriculture sector, which makes up 36% of the gross domestic product (GDP) and 35% of total export earnings, employing 63% of the total labor force. With about 20 million ha of total arable land, a projected population of 60 million in 2010, and 2% population growth rate, the agriculture sector will continue to play a very significant role in the future. Therefore, its first and foremost objective is to develop and promote economic sectors based on agriculture. For the development of the agriculture sector itself, increasing productivity and improving product quality are two principal objectives.

Soils and climatic conditions in many parts of Myanmar favor cultivation of rice, the principal agricultural crop. Rice is the staple food of the entire population and per capita rice consumption Myanmar is one of the highest in the world. Myanmar is a rice-surplus country. It is planned to increase the rice cultivation area to 8.09 million ha.

Rice production in the country has already increased significantly due to the introduction of summer rice in 1.22 million ha as well as the use of high-yielding, or modern, crop varieties (MVs), hybrid seeds of vegetables, and associated technologies.

Since Myanmar is the home of many tropical crop species, their genetic diversity is immense. However, with the introduction of MVs, the continued existence of these genetic resources is at risk. Destruction of the habitat of wild species and related genera by rapid urbanization can also be expected in the very near future. Socioeconomic issues and unsustainable agricultural practices are additional threats to agricultural biodiversity. In order to prevent the permanent losses of genetic diversity for many tropical crop species, plant genetic resources management, conservation, and utilization research activities are critical issues for Myanmar agriculture.

The fishery sector plays an important role in providing food and income, contributing to the social and economic status of Myanmar. Thus, it is essential to conserve the country's 0.5 million hectares of coastal wetlands that provide the essential spawning grounds, nursery areas, and feeding grounds for marine and brackishwater fauna.

3. Climate Change in Myanmar

3.1 Climate

Myanmar's climate is greatly influenced by the tropical monsoon circulating system. The Rakhine Mountains, bordering Bangladesh and India, obstruct the southwest monsoon from central Myanmar, which is consequently semi-arid, characterized by summer temperatures above 40˚C and low annual rainfall of about 500 mm.

During the winter and summer seasons, the northeast monsoon winds bring pronounced cold weather with occasional rain falls to the northern parts of Myanmar and hilly regions, while other parts are moderately cold. Rainfall is influenced also by the locality. The coastal regions receive about 5,000 mm of annual rainfall. In the far north there are snow-capped mountains.

3.2 Climate Change

Climate change impacts are likely in the tropical coastal regions due to global warming as projected in reports by the Intergovernmental Panel on Climate Change. The increasing frequency of cyclones and accompanying strong winds, storm surge, floods or inundation, intense rains, extreme temperatures, droughts, and sea-level rise are evidence of climate change-related impacts to which Myanmar has to pay serious attention.

3.3 Natural disasters

Myanmar lies in a climatic zone that is frequently subjected to cyclones and river flooding. The former occur periodically, but unpredictably and cause extensive damage to property, soils, and crops, and take a heavy toll on human and animal lives. Flooding, sometimes caused by cyclones, but more often by excessive precipitation in the mountainous watersheds, is a regular feature of Myanmar's extensive floodplains. Each year, 2 million ha of land are severely flooded and another 3.25 million ha are moderately inundated. These floods reduce agricultural production, cause erosion and sediment loading, and spread infectious disease. Finally, much of upper Myanmar lies in a tectonically active zone.

During the last four decades, Myanmar had five major cyclones: Sittwe in 1968, Pathein in 1975, Gwa in 1982, Maungdaw in 1994, Cyclone in 2006 and Nargis in 2008. Nargis, which struck Ayeyarwady Delta and the eastern part of Yangon in Yangon Division with a wind speed of over 260 km per hour, and the associated floods, caused the deaths of over 100,000 people, as well as massive physical destruction of mangroves, agricultural fields, houses, and utility infrastructure. Furthermore, flooding, especially of saltwater into agricultural lands and freshwater bodies, caused further extensive economic, social, and environmental damage.

In central Myanmar, streams that are often dry are subject to flash floods caused by heavy rain in the upper watersheds, resulting in drowning of people and livestock and destroying infrastructure.

However, projected increasing temperature and decreasing rainfall in central Myanmar under climate change may lead to the expansion of the country's dry zone, in which annual rainfall is less than 1,000 mm.

3.4 Vulnerability of Different Sectors to Climate Change

Agriculture. Severe climate change effects could affect the country's production of rice and other crops on which the population depends. Climate change might also affect

local varieties, already endangered due to replacement with MVs, urbanization, deforestation, and growing population pressure.

Forestry. Myanmar's forest areas have been destroyed by cyclones, strong winds, floods, extreme temperatures, and droughts in addition to human pressure. The dominant forest type is the deciduous forest that sheds leaves during the dry season when the climate is extremely hot and catches fire easily. Forest fires are becoming more severe, killing wildlife. Climate change is likely to cause increased dryness—as well as wetness—and thereby affect the survival of flora and fauna.

Biodiversity. Myanmar is often cited as the last frontier of global biodiversity in Asia. By their nature, forests are highly vulnerable to climate extremes such as warming and drought. Many species of fauna and flora are highly endangered. Strenuous efforts to maintain the network of protected areas are needed to prevent biodiversity loss.

Mangrove Ecosystems. In some coastal areas of Asia, a 30 cm rise in sea level can result in 45 meters of landward erosion (Tun, 2009). Sea-level rise tends to aggravate the currently eroding coastal areas; thus, mangrove forests and swamp areas along the Myanmar coast are facing degradation. Loss of mangrove ecosystems means loss of the valuable products and ecosystem services mentioned earlier.

Coral Reefs. The vast and diverse coral reefs of Myeik Archipelago are of immense ecological and economic importance for the country. Sea-level rise is likely to significantly affect the social and economic situation of coastal areas like the Myeik Archipelago. If the corals die due to high temperature-induced bleaching, the production of lucrative fish and the farming of fish, pearl oysters, deep sea lobster, and seaweed will all be affected. Some species of marine fish may disappear or move to colder regions, as will some native species of whales and dolphins.

Coastal Erosion. Many sandy beaches along the coastal areas of Myanmar already face problems of coastal erosion due to structural development, changes in living patterns, and recreational activities, including ecotourism. Such activities are affecting marine turtle nesting beaches, such as Maungmakan beach in Taninthayi Division. Such degraded areas are highly vulnerable to climate change hazards.

Some of the islands located on the Rakhine coast that are important areas for marine fisheries production are also affected by waves during the monsoon season. In Thandwe District, two out of three villages have already been displaced by coastal erosion. In the monsoon season, some residents move to other villages and some seek shelter at the monastery in their village. This situation will be worsened as sea level rises under climate change.

3.5 Needs and Concerns Arising from Adverse Effects of Climate Change

The loss and damages due to Cyclone Nargis in the Ayeyarwady Delta reflect, to a certain extent, the vulnerability of Myanmar to climate extremes. As a developing country, people's livelihoods mainly depend on favorable climate conditions and availability of natural resources, such as land, water, and forest resources.

In the agricultural sector, late monsoon onset will delay agricultural cycles, such as soil preparation for paddy cultivation. This delay will disturb crop growth in the subsequent months. During the growing season, abnormal weather will damage the crops. In the harvesting period, adverse climate can damage the ripening crop.

Disruption in agricultural activities will affect the socioeconomic development of the country through increasing prices of basic commodities and transport. For example, during the relief and recovery period after Cyclone Nargis, the prices of basic food items rose significantly, because of the fear that there would be decreased food supply from the Ayeyarwady Delta. In fact, rice production from the delta contributes only about 10% of the country's total rice consumption. Nevertheless, this fear remained for several months, keeping prices high.

Freshwater resources in the coastal areas are mainly the impounded waters in ponds and reservoirs and groundwater. In the event of cyclones, freshwater storage facilities are damaged by strong winds and seawater inundation. Also there is disruption of municipal water supplies and groundwater supply owing to problems in electricity supply. Water shortages cause a number of problems, especially in urban areas where hygiene levels become low and can result in outbreak of diseases.

In the event of climate extremes, forests are vulnerable not only to climate change but also are at high risk of being over-exploited. If climate-sensitive sectors, such as agriculture, livestock, and fisheries are largely disrupted by climate extremes, food security of rural communities could be impaired. Under such situations, they would

have no alternative but to turn to the forests for intensified exploitation of wood and non-timber products for their survival and livelihood, and could finally destroy the forests.

4. Conclusion

Myanmar, a tropical coastal country, with north-south running mountain ranges and river systems, is endowed with substantial water resources mainly due to the southwest monsoon. It is rich in biodiversity due to the extensive forest cover. Myanmar has fertile river valleys, an extensive deltaic plain, and a long coast line with diverse marine resources.

Measures are being taken by the Government to ensure the country's food security, which is one of the principal requisites for national development. There have been improvements in the irrigation system, such as construction of new reservoirs and dams, installation of more river pumping stations, and increased groundwater harvesting. Systematic use of fertilizers and introduction of some advanced agricultural technologies are also being undertaken. Summer rice production and wetland cultivation in addition to rained cultivation are promoted. However, adaptation plans for this sector should be further enhanced for increased earning of foreign exchange and national economic development.

The climate is generally favorable for various agricultural practices, growth of forests, and development of fishing industries, all of which support the livelihood of majority of the population. Extreme events and climate variability disrupt the livelihoods of rural populace, particularly farmers, and affect national development. Cyclones from the Bay of Bengal usually cross the Rakhine coast at least about once in every two years. Floods and droughts in certain areas occur annually. The landfall of Cyclone Nargis in 2008 over the Ayeyarwady Delta demonstrated that Myanmar is vulnerable to cyclones originated in the Bay of Bengal, although presently rare.

To reduce vulnerability to climate change, policies, legislation, and other supporting tools need to be developed by government agencies in a coordinated manner. This will help identify and implement adaptation strategies toward a peaceful modern country. For this purpose, institutional strengthening, technology innovation and transfer, provision of advanced tools and equipment, enabling condition with adequate funds, and collaboration with relevant national, regional, and international institutions and agencies are indispensable.

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