A new land cover map for the Mekong:
Southeast Asia's largest transboundary river basin

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Abstract: The transboundary Mekong basin, including territorial parts of China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, is endowed with a rich natural resource base. The rapid socio-economic development of the region, however, substantially increases pressure on its natural resources that are increasingly subject of over-exploitation and environmental degradation. Some of the main environmental problems facing the region are common or transboundary issues that only can be addressed by transboundary approaches based on consistent and regional comparable information on the state of the environment at basin scale. In this context, a regional specific land cover map, the MEKONG LC2010 product, was produced for the entire Mekong Basin, utilising information from the MODIS sensor aboard the platforms Aqua and Terra.

Keywords: Mekong Basin, land use, land cover, environment, remote sensing

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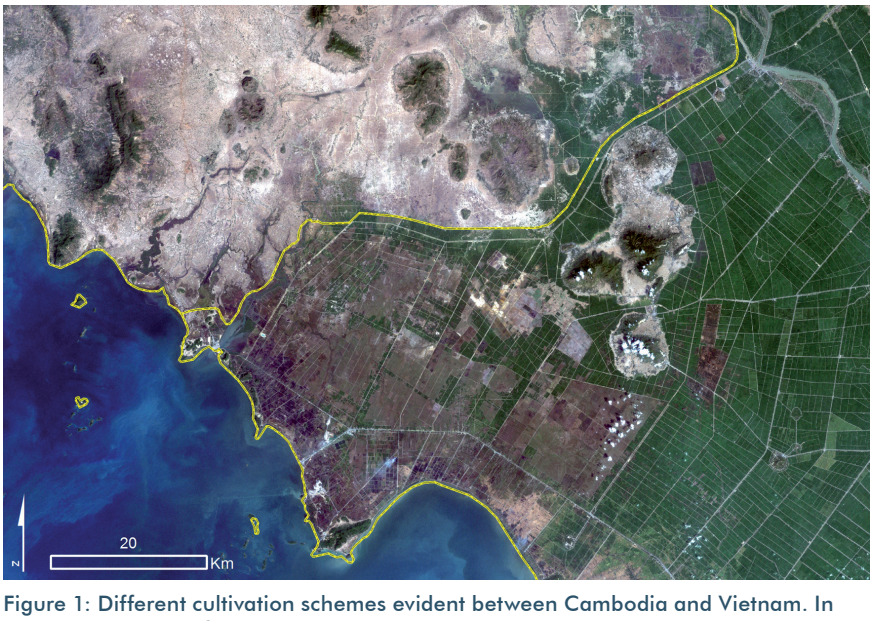
The Mekong Basin and its environmental challenges

The basin of the Mekong River in Southeast Asia includes territorial parts of six countries: namely China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. The Mekong is, with an estimated length of 4,350 km, the world's twelfth longest river and its basin spans a total area of approximately 795,000 km². The Mekong has its source in China's Qinghai Tibetan plateau at an elevation of 5,200m, then flows for approximately 1,900 km through the steep gorges and narrow valleys of Tibet and Yunnan Province of China, towards the border of Laos and Myanmar. By this stage, the river has already lost more than 4500 m elevation. From this point on, the terrain becomes increasingly moderate along the river's southwards course. The river forms the boundary between Laos and Thailand whereby intensively cultivated planes of cropland in Thailand in contrast to less intensively managed areas in Laos are evident. Further downstream, the river enters the alluvial lowlands of Cambodia where the river is linked to the very sensitive flood pulse system of the Tonle Sap ecosystem. In Vietnam the Mekong finally divides into nine tributaries forming the Mekong Delta before emptying into the South China Sea (Kuenzer und Renaud 2012).

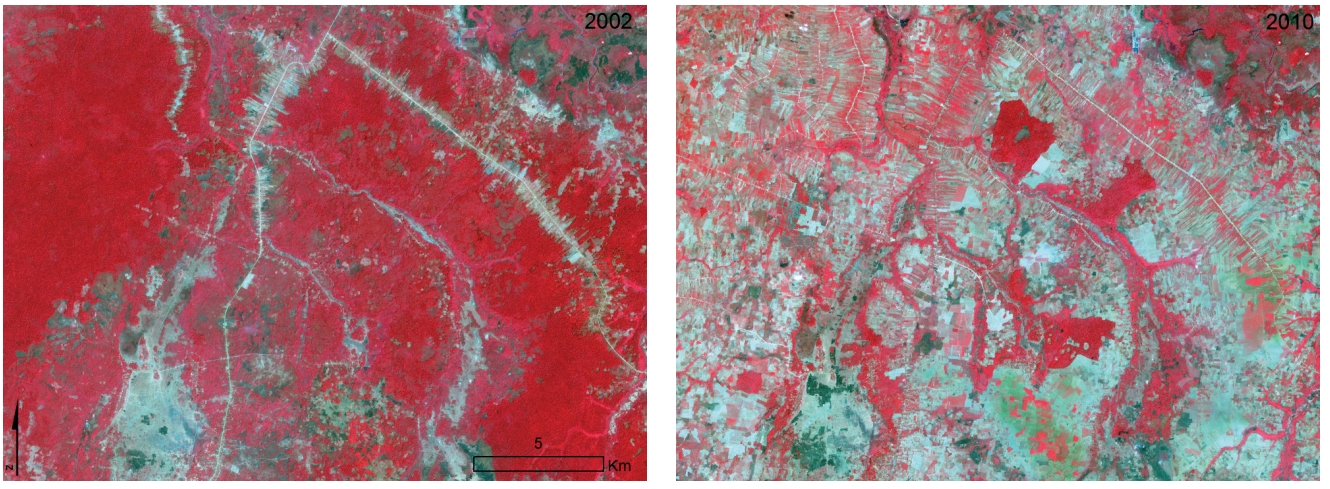
The Basin is home to a population of more than 72 million inhabitants who are directly or indirectly dependent on the quality and quantity of its natural resources. These resources have historically supported rural livelihoods in the region and underpin the rapid socio-economic development, which has occurred in the Mekong region over the past decades. Today, it is one of the world's fastest-growing regions in terms of economy and population, though an uneven development is apparent between the riparian states. The rapid socio-economic growth has, however, also substantially increased pressure on the basin's natural resources. Weak environmental governance, poor law enforcement, and corruption further contribute to the over-exploitation and degradation of the environment.

With the transition from subsistence farming to more diversified economies, the governments of the riparian countries are eager to promote the commercialization of agriculture and agro-processing in order to raise incomes and create employment (Rowcroft 2008). This development is further compounded by the growing population that stimulates the demand for



Source: Landsat TM satellite data 2009

Figure 1: Different cultivation schemes evident between Cambodia and Vietnam. In Cambodia (upper left corner) cropland is harvested once per year, while in Vietnam (lower right corner) cropland is intensified up to three harvests per year.



Source: ASTER satellite data 2002 and 2010

Figure 2: Conversion of natural forests to cultivated areas near Kampong Reang, Cambodia. The scenes are displayed as colour infrared (CIR) images for a better differentiation of vegetation structures.

land and agricultural products. As a consequence, natural ecosystems, and in particular accessible lowland forests and woodlands, are facing increased pressure through the expansion of farmland and industrial crop plantations. Particularly in the economically powerful countries in the region, changes in cropping patterns (e.g. the shift from traditional crops to cash-cops or aquaculture) and intensities (e.g. the shift from one harvest to multiple harvests per year) are well observed phenomena (Vo et al. 2013, Kuenzer and Knauer 2013). The effects of economic development, knowledge, and technology on land use patterns, are for example, clearly evident along the Cambodian-Vietnamese border (figure 1): While soil and climatic conditions are about the same here for both countries, on the Vietnamese side, modern, early maturing, irrigated rice varieties are cultivated for the world market with up to three harvests per year. On the Cambodian side, however, less intensively managed and non-irrigated single season rice crops dominate due to the lack of agricultural knowledge and technology, which were lost as a consequence of the Khmer Rouge regime. Although these highly efficient agricultural practices allow for higher yields and revenues, it is important to note that very intensive farming, inappropriate irrigation, the increased use of fertilizers and pesticides (Toan et al. 2013), and the trend to mono-species cash-crop cultivation may cause an inevitable deterioration of water and soils as well as endangering the ecological equilibrium in the long term.

Another transformation the region has experienced over the last decades is the transition from state-directed economies to more open, market-based economies which has been accompanied by a rapid expansion of commercial relations among the Mekong countries (Rowcroft 2008). With the intensification of transboundary and international trade, however, environmental change may also be induced by drivers from abroad. Thailand for example, imposed a strict logging ban in 1989 after a series of devastating floods and landslides as a result of deforestation by the timber industry. Consequently, timber imports from Thailand's neighboring countries increased rapidly in subsequent years, whereby the environmental threats related to unsustainable forest losses where outsourced. Commercial logging intensified particularly in Laos, where wood products accounted for 56% of the official export revenue by 1991 (Daoroung 1997, Heinimann 2006). A more current transboundary phenomenon is the boom in rubber plantations that Laos has been experiencing over the past few years, mainly in response to a rising market demand for rubber from its neighboring countries, primarily China. As a result, many secondary forest formations and shrublands in the highlands of Laos, which play an important role in securing the livelihoods of local people (Heinimann 2006), have been converted to mono-species rubber plantations which only provide a fraction of ecosystem services compared to natural forests.

The increased transboundary trade is also coupled with the growth of urban structures and infrastructure (Leinenkugel et al. 2011). The promotion of new economic corridors as part of the Greater Mekong Subregion (GMS) programme initiated by the Asian Development Bank, is, for example, accompanied by substantial infrastructure developments valued at about US$11 billion, that have already been completed or are being implemented (ADB 2013). Among these developments are the upgrading of the Phnom Penh-Ho Chi Minh City highway and the East-West Economic Corridor that will eventually extend from the Andaman Sea to Da Nang in Vietnam. Such infrastructure projects have a direct and indirect impact on the land cover in the region. Directly, due to losses of mostly natural vegetation related to road constructions, and indirectly, because new roads facilitate the physical access to markets and natural resources, and thereby alter economic values (Rowcroft 2008). As a result, formerly remote regions are increasingly becoming a potential for profit with their conversion into managed land, as is evident in figure 2.

Furthermore, the rapid socio-economic development is accompanied by increasing energy demands, which are expected to rise by 7 % over the next 20 years, alone in the lower Mekong Basin (Kuenzer et al. 2012). China is implementing a number of hydropower projects along the Mekong main stem, the so-called "dam cascade" to meet its enormous demand for energy. Additionally, Laos and Cambodia are planning more than 100 dams on the Mekong tributaries to harness the river's hydropower generating capacity more effectively. The environmental consequences, particularly the transboundary impacts, are being controversially discussed and have brought the Mekong into public and an international focus through

the media. The downstream countries, believe that the dams are responsible for the alteration to the overall flow of the Mekong and its sedimentation. In the long-term, these may result in high environmental and social costs due to bank erosion, water shortage, increased irrigation challenges, and shifts in biodiversity (Kuenzer et al. 2012). In particular, the dams are expected to impede nutrient-rich sediment from settling in the Mekong delta and the Tonle Sap floodplain, which are essential for farming, fishery, and the prevention of saltwater intrusion into the Mekong Delta (Kuenzer et al. 2012, Kuenzer et al. 2013a). Furthermore, the dams are expected to block fish migration routes, which again, in the long term, will increase pressure both on cropland and areas for livestock farming (Kuenzer 2013).

The need for a regional perspective

Thanks to the shared natural resources and increased social and economic interactions between the riparian states, the basin can increasingly be seen as an integrated region with some of the main environmental problems being common or transboundary issues (UNEP and TEI). The Thai logging ban or the Chinese dam cascade illustrate to what extent shifts in land cover policies and practices in one country, can lead directly or indirectly to profound changes in another country's natural resources, economic conditions, or political and economic dependencies. Notably, however, the very heterogenic political, economic, institutional, and cultural conditions between the riparian countries have led to very diverse perceptions and practices in terms of natural resource exploitation and conservation (Heiniman 2006). Therefore, coordinated, trans-boundary management plans that not only correspond to specific environmental and social conditions on local or national scales but also contribute towards a sustainable development of the entire Mekong region are essential (Renaud and Kuenzer 2012, Moder et al. 2012). Furthermore, the inter-dependency between water, land, and other related natural resources requires a perspective encompassing all environmental aspects of the basin following the principles of Integrated Water Resource Management (IWRM) (Moder et al. 2012). This is exemplified by the WISDOM Project, a bilateral research project between Germany and Vietnam (http://www.wisdom.eoc.dlr.de/), which has brought together more than 60 scientists from the fields of hydrology, sociology, information technology, and earth observation aiming at the analysis of socio-environmental issues in the Mekong Basin and the Mekong Delta, in particular. The WISDOM project also initiated the first transboundary conference on the Mekong Region- the Mekong Environmental Symposium, held in Ho Chi Minh City in March 2013, which highlighted the need for consistent and regionally comparable information on the state of the environment across all riparian countries.

A crucial information base that is used to characterize the state of the environment is provided by so-called land cover maps which categorize and quantify the environment according to the discernible vegetation (e.g. forest, grassland), hydrologic (e.g. wetlands, water bodies) or anthropogenic features (e.g. cropland, urban areas) on the land surface. Generally, these land cover maps are derived by the use of satellite imagery and are essential to many geo-scientific applications as seen in the fields of agriculture, ecosystems, biodiversity, climate, health, or energy. Furthermore, stakeholders, decision makers, international organizations, research networks, donor agencies, and others, require regional land cover and land use maps as essential baseline information for reporting and monitoring purposes.

Most government agencies, howe-

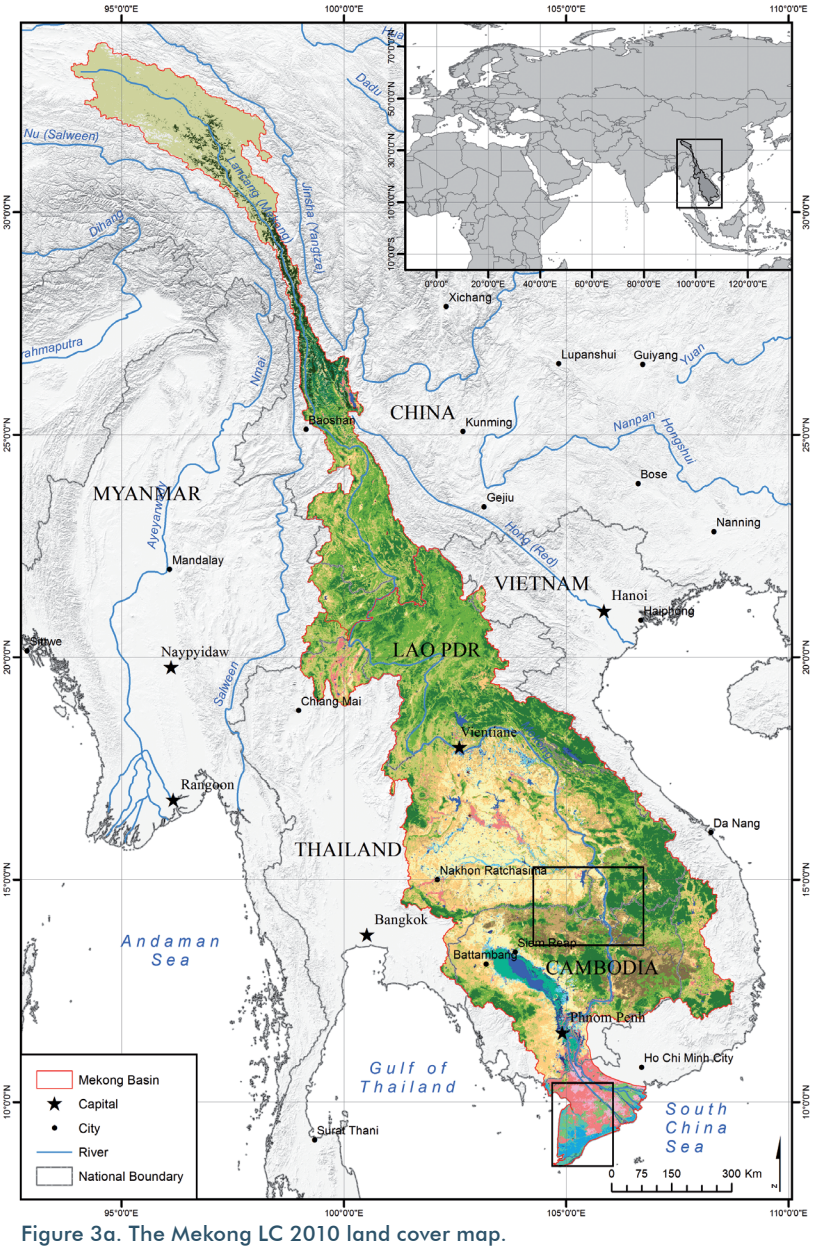


Figure 3a. The Mekong LC 2010 land cover map.

ver, only produce maps that are limited to the extent of their respective national territories and thus, cannot be used for transboundary purposes. The combination and harmonisation of such independent, national land cover maps is generally accompanied by difficulties related to information gaps or thematic incompatibilities and, thus, limit their usefulness for regional, transboundary assessments. On the other hand, regional land cover maps produced over the last two decades that focus explicitly on continental Southeast Asia, also have certain limitations which hamper their applicability for present basin-wide land cover analyses. Many products only focus on a specific topic such as the characterisation and quantification of forest cover, having no or very little information on the remaining land cover characteristics (Leinenkugel et al. 2013). The most recent map having a broader and more comprehensive land cover classification scheme was produced for the year 2000 and has consequently become obsolete for present requirements. Moreover, all regionally specific maps covering continental Southeast Asia exclude the territory of China, thereby effectively providing land cover information solely for the lower Mekong Basin. The option of using subsets of global land cover maps has also shown to be inappropriate since these insufficiently capture the regional heterogeneity in land cover characteristics on local scales (Leinenkugel et al. 2013, Kuenzer et al. 2013).

The Mekong LC2010 land cover map

Within this context, a detailed land cover map for the year 2010, the MEKONG LC2010 product, was produced for the entire Mekong Basin, within the framework of the WISDOM project (figure 3). This land cover map is based on satellite data from the Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra and Aqua satellites that provide nearly full daily coverage of the Earth at a spatial resolution of 250-1000 m, being well suited for regional- to global-scale terrestrial environmental monitoring. The MEKONG LC2010 map addresses sub-regional characteristics by the inclusion of locally specific land cover classes, such as alpine grasslands, mangrove forests, or aquaculture while simultaneously ensuring a consistent classification of basin wide land cover types, such as evergreen or deciduous broadleaved forests. Furthermore, the temporal growing stages of the vegetation cover (land surface phenology) were analysed by a synthesis of near-daily satellite observations, which allowed for the differentiation between cropping intensities over cultivated land.

The Mekong LC2010 product, produced and provided by the team "Land Surface Dynamics" at the Earth Observation Center, EOC, at the German Aerospace Center, DLR, is freely available upon request and a comprehensive scientific description of the product can be found in Leinenkugel et al. (2013). Next to the production of single date land cover maps, current activities in the team involve the production of annual canopy cover maps from 2000 onwards. These maps focus particularly on woody land cover types and allow for the continuous monitoring and analysis of the valuable forests and woodlands in the Basin throughout the last decade.

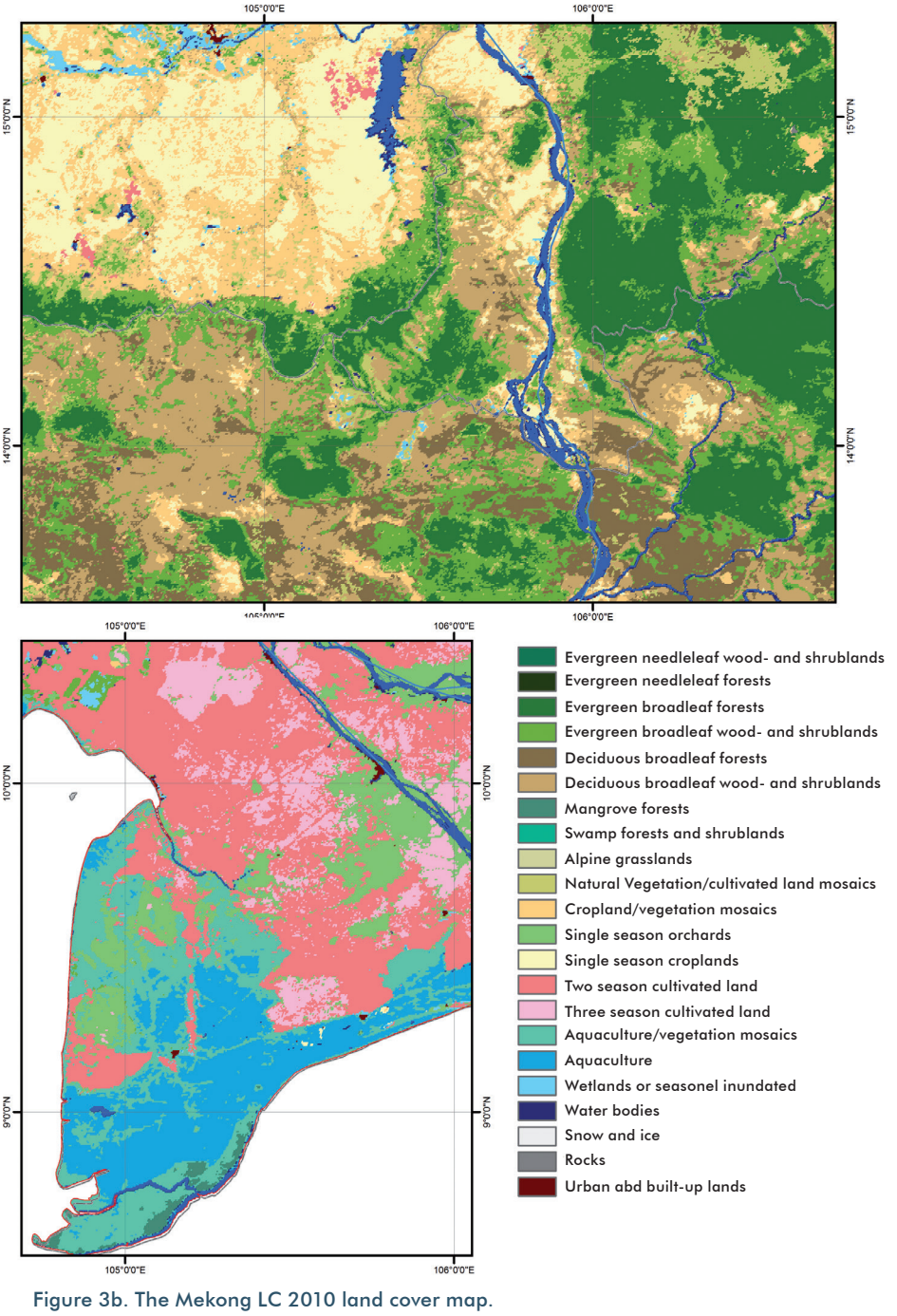


Figure 3b. The Mekong LC 2010 land cover map.

Conclusion

The transboundary Mekong Basin in South East Asia is endowed with rich natural resources that are increasingly subjected to much pressure from the rapid socio-economic development within the region. Although geographically, culturally, economically and politically diverse, growing transboundary trade and the increased exploitation of shared natural resources have transformed the Basin into an integrated economic region. In this respect, it is inevitable that the Mekong riparian countries are keen to promote a sub-regional dialog to maintain the balance between economic development on the one hand, and the need for ecological protection and conservation on the other (Kuenezer et al. 2012, Moder et al 2012, Renaud and Kuenzer 2012). The establishment of regional and transboundary environmentally related institutions and programmes, such as the Mekong River Commission or the Core Environment Program and Biodiversity Conservation Corridors Initiative (CEP-BCI) of the Greater Mekong Subregion, has shown that the significance of transboundary cooperation for promoting sustainable growth in the region has been acknowledged. However, regionally consistent information on the state of the environment for the entire basin is still rare, and either not accessible or outdated. In view of this, the Mekong LC2010 product, being the only current basin-specific transboundary information data set on the land cover distribution in the area, provides scientists, stakeholders, and decision-makers with an updated and comprehensive picture of the diverse land cover characteristics of the region. As the first regional specific land cover product covering both the lower and the upper Mekong Basin, the Mekong LC2010 map is also of particular value for basin-wide hydrological modeling in the context of integrated water resource management (IWRM).

The Tibetan Plateau, where the Mekong originates, is predominantly covered by alpine grass- and rangeland. Below the tree line, at approximately 4000 m, needleleaved forest formations and shrubland become dominant which increasingly give way to broadleaved evergreen forests and woodlands, from elevations at 2000-2500m downwards. Particularly in the more densely populated southern part of Yunnan province and northern Laos, however, large extents of these evergreen forests have been degraded by small scale shifting cultivation practices, resulting in very heterogenic patterns forests and forest regrowth interspersed with patches of shrub-, grass-, and cropland. The land cover distribution in the lowlands of Laos and Cambodia shows lower proportions of evergreen vegetation but higher distributions of cropland, cropland/vegetation mosaics, and dry-deciduous broadleaved wood- and scrublands. Intensive cultivated areas, mainly rice cultivation, are concentrated in the Mekong Delta, in the lowlands surrounding Tonle Sap Lake, and in the extensive plains of the Khorat Plateau in Thailand. In the Mekong Delta double- and triple-season rice paddies, orchard cultivation, aquaculture, coastal mangrove forests, and mixtures of the latter, known as integrated shrimp-mangrove farming systems dominate.

Box 1: Land cover distribution in the Mekong Basin

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