International Journal of Applied Geospatial Research
Volume 8 • Issue 3 • July-September 2017

Food System Resilience and Sustainability in Cambodia

Joseph Messina, Department of Geography, Environment, and Spatial Sciences, Michigan State University, East Lansing, MI, USA
Tanita Suepa, Geo-Informatics and Space Technology Development Agency (GISTDA), Bangkok, Thailand
Sieglinde Snapp, Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI, USA
Jennifer Olson, Michigan State University, East Lansing, MI, USA
A. Pouyan Nejadhashemi, Department of Biosystems and Agricultural Engineering, Michigan State University, East Lansing, MI, USA
Sarah Murray, Michigan State University, East Lansing, MI, USA
Nathan Moore, Department of Geography, Environment, and Spatial Sciences, Michigan State University, East Lansing, MI, USA
April Frake, Department of Geography, Environment, and Spatial Sciences, Michigan State University, East Lansing, MI, USA
Peilei Fan, Michigan State University, East Lansing, MI, USA
Umesh Adhikari, Department of Biosystems and Agricultural Engineering, Michigan State University, East Lansing, MI, USA

ABSTRACT

Cambodia is witnessing a “Goldilocks moment” in demographic change concurrent with shifts in land use, hydrology, and climate. These trends interact and affect food production, food costs, and food security. Drivers of these trends are typically examined separately with interacting factors considered along disciplinary margins. While science models to explore these interacting effects have been proposed, there remains an applied research gap in integrating these pieces and assessing interdisciplinary opportunities for developing food security solutions. Developed following a request from USAID to elucidate food security conditions in Cambodia, here the authors present their geospatial synthesis of the biophysical and socioeconomic drivers of current food security risk, as well as explore future trends for those conditions. The overall structure shows several interlocking or mutually reinforcing trends in systems that point towards a significant intensification of food insecurity in the near future. They offer an assessment of future targets for food systems innovation.

KEYWORDS

Cambodia, Climate Change, Food Security

INTRODUCTION

Since 1990, substantial progress has been made in the fight against global hunger, yet the state of hunger in many developing countries remains at a critical level. According to the Food and Agriculture Organization of the United Nations (FAO), 805 million people still suffer from undernourishment, many of whom are small-holder farmers, dependent on agriculture (GHI, 2014). In recent years, food insecurity exacerbated by continuous population expansion has placed a much greater emphasis on the

DOI: 10.4018/ijagr.2017070104

global agricultural sector in an effort to expand production. Yet what remains to be fully understood are the direct impacts on global, national, and local food systems in light of a changing climate where unpredictable precipitation patterns and droughts influence annual agricultural yields. As climate patterns continue to shift, so too will the geographic distribution of vulnerability and risk for food insecurity. As such, a growing emphasis exists on the development of actionable adaptation strategies aimed at improving food security conditions in light of changing climatic conditions.

Across South East Asia, climate change is one of the most significant synoptic drivers of population scale risks in vulnerability, resilience, and adaptation. In climate change adaptation research identifying actionable research is critical. It is relatively easy to identify well-known but generally intractable problems; however, these fail to offer effective guidance for donor institutions. In this study, guidance regarding the most pressing gaps in knowledge, methods, and data that stand as obstacles to improving food security under climate change conditions are considered for the country of Cambodia, one of the poorest countries in South East Asia. A tractable innovation pipeline, presented as a list of action items is presented by precedence and potential impact. While not meant to be exhaustive, the innovation pipeline presented herein is meant to offer suggestions for mitigating future food insecurity issues directly linked to a changing climate.

CAMBODIA

Cambodia is located in the southern portion of the Indochina Peninsula and shares borders with Vietnam, Laos, and Thailand, with the Gulf of Thailand to the south. Consisting primarily of low plains, the region is bounded by a highland region formed by two distinct upland blocks, the Cardamom Mountains and the Elephant Mountains that cover much of the area between the Gulf of Thailand and the Tonle Sap in the southwest. Elevations exceed 1,500 meters only in the Cardamom range in the southwest and in the Annamite range on the borders in the northeast. Tonle Sap Basin, the Mekong Lowlands, and the Mekong Delta cover roughly 75% of the country with elevations usually less than 100 meters above sea level. The coastal zone in the southwest of the country has a total length of 435 km. Human modification of the Mekong is having significant impacts on the Tonle Sap seasonal flooding (Kummu and Sarkkula 2008) and follow-on effects for the ecosystem as a whole (Arias et al. 2014).

LAND COVER CHANGE

Outside of the densely populated plains the land is mostly forested, and a large percentage of that land has protected status. Indigenous communities reside in these areas but do not have clear land tenure rights. Land tenure remains a controversial issue. Many property deeds were destroyed in the 1970s civil war, and it is estimated that only one-third of the agricultural population has proper title. Recent land concessions to large-scale private agro-industrial entities have increased feelings of land tenure insecurity, potentially affecting rural settlement patterns (Kizlovkis 2014).

In recent years the extent of forest and other wooded land has fallen rapidly due in part both to deforestation and the conversion to agro-industrial crop plantations such as rubber, oil palm, cassava and jatropha, as well as sugar cane and biofuel crops (Bansok et al., 2011). Figure 1 shows an assessment of areas of forest change and the main reason for the forest cover changes (Broadhead & Izquierdo, 2010).

Agricultural expansion and the majority of areas converted are listed as having been primary forest. Almost half of the sites recorded were in protected areas or national parks. Between 1965 and 2010 forest cover in Cambodia fell from 73% to 57% of the total land area (12,944 to 10,094 thousand hectares) (Figure 2) (Bansok et al., 2011). Most areas of forest loss in Cambodia are in the hilly zones and along the mountain ranges with evergreen and semi evergreen forests (Broadhead & Izquierdo, 2010). In addition to the reduction in area of forest, the quality of forests has declined.

Figure 1. Assessment of forest change from 1973-2014. Black areas represent zones of dense forest converted to non-forested areas. Data source: Atlas of Cambodia, 2015.

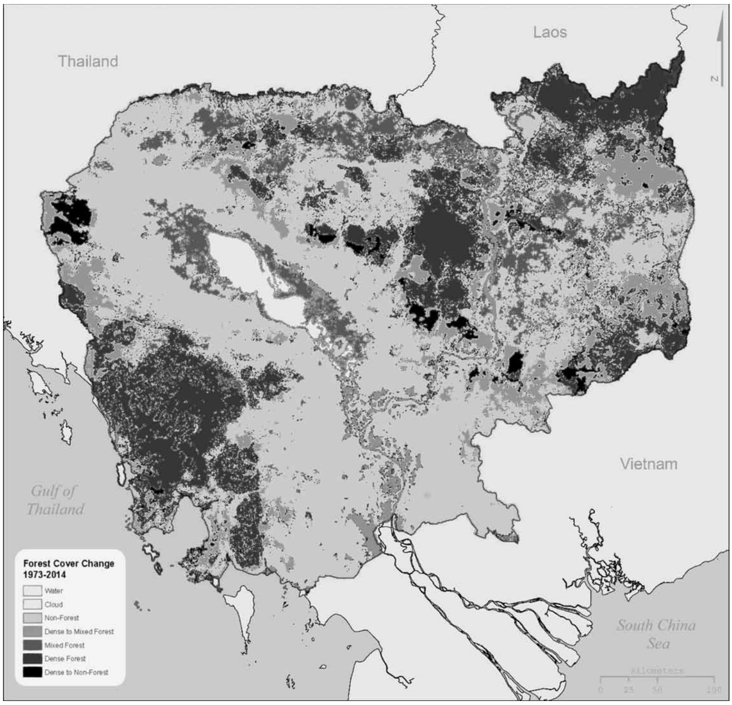
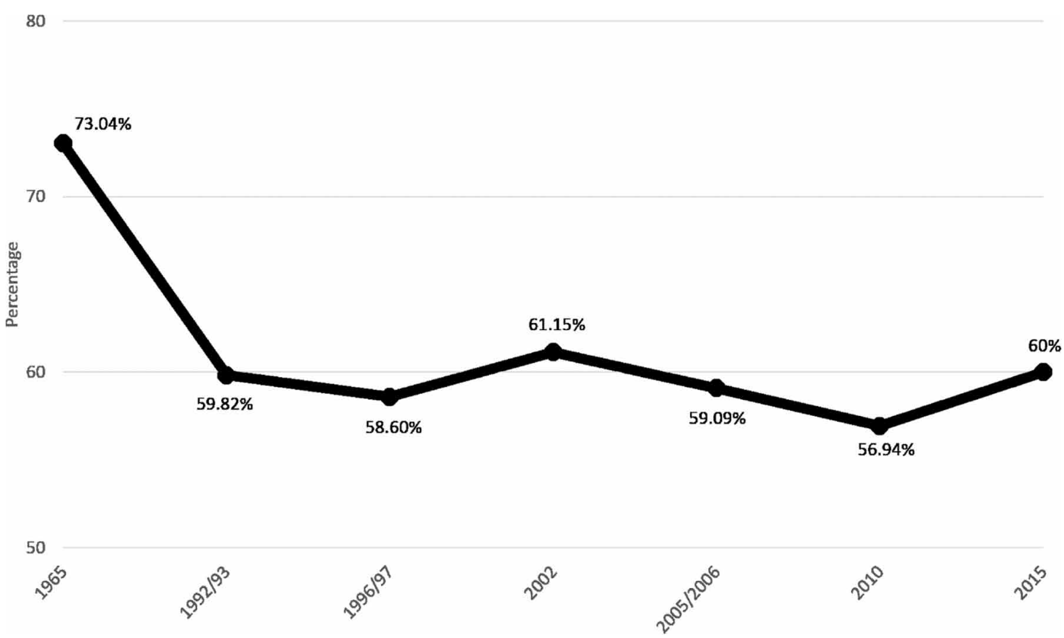


Figure 2. Changes in forest cover, 1965-2015. Data source: Bansok et al., 2011.



Through its rich biodiversity and productivity, both in terms of plant and fish communities, the Tonle Sap Lake serves as a resource base for the national economy of Cambodia; nearly half the Cambodian population depends on the lake's resources. In this way, the Tonle Sap Lake has enormous significance on socio-economic development in Cambodia (Senevirathne et al., 2010). The Land Use and Land Cover Change (LULCC) of the Tonle Sap watershed was studied by Senevirathne et al. (2010) using remote sensing satellites (LANDSAT and ALOS) to analyze LULCC over the period of 1990-2009. Study findings revealed that the most prominent change trajectories occurring within the watershed were deforestation and expansion of agricultural areas, both of which could affect the biosphere and availability of natural resources for the Cambodian people. Deforestation in the flooded forests around the lake has destroyed extensive tracks of wet-season fish habitat. Logging in the upper watersheds sends silt downstream, clogging the mouth of the lake, and can result in downstream floods. If the deforestation continues at current rate (2.26% per year), the forest cover will be eliminated in 25 years (Senevirathne et al., 2010).

The Mekong region also has experienced extensive loss of primary forest (FAO, 2005; Leinenkugel et al. 2015). Empirical evidence shows that a high percentage of illegal logging, commercial logging and fuel-wood collection for heating and cooking are the leading causes of deforestation in the Mekong sub-region (World Bank, 2006). ADB (2000) pointed out that the actual deforestation rate for the coming decades depends on three factors: changes in market demand, changes in forestry management, and changes in spontaneous growth of agricultural settlement.

AGRICULTURE

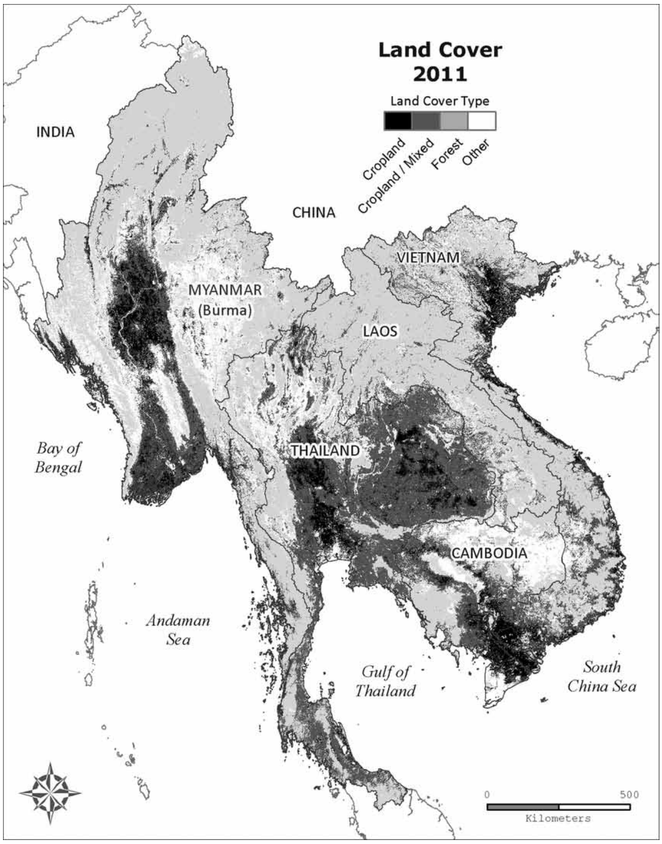
Agriculture is expanding rapidly and is the mainstay of the Cambodian national economy contributing 36% to the national Gross Domestic Product (GDP) while providing employment to 72% of the population (FAO, 2013a). GDP in 2010 was $11.2 billion, with GDP per capita around $790 (Thomas et al., 2013). In recent years, Cambodia's economy has grown substantially, with average annual GDP growth approaching 9.5% for the 10-year period ending in 2008 (Theng and Koy, 2010). Much of this economic growth is due to non-agricultural changes including policy changes, tourism growth, and economic diversification. Engagement with China and other trading partners together with policy changes and increasing foreign direct investment appear to have promoted this shift (Saing et al. 2012).

Cambodia can be divided into four agro-ecological zones with differences in geography and environment: Coastal, Plain, Plateau/Mountainous, and Tonle Sap (Bansok et al., 2011). According to the 2008 Census, 81.7% of the households in Cambodia live in rural areas (RGC, NIS, 2009). With such a large rural population, most people are highly dependent on agriculture (Thomas et al., 2013), yet the land available for the country's agrarian smallholder sector is becoming increasingly scarce (Scheidel et al., 2013) (Figure 3). In addition, the young age and changing economic conditions of the country has resulted in internal "Migration [being] a natural consequence of the context in which the country now finds itself (UNFPA, 2012, p. 93)."

In 2010, the composition of the agricultural sector was crop production (54%), fisheries (27%), livestock (13%) and forest products (6%) (Ministry of Agriculture, Fishery and Forestry, Royal Government of Cambodia, Annual Report, 2011). The share of agriculture represented by field crops has been increasing over the last decade, up from 40% in 2001, to 54% in 2010. Likewise, the lowland areas around Tonle Sap Lake and the Upper and Lower Mekong have played an important role in the tremendous increase in rice production in Cambodia, roughly doubling between 2000 and 2010 (FAO, 2011). Rice is the dominant wet season crop in the country, occupying over 85% of the cultivated area (Bansok et al., 2011). Agricultural sector growth, especially rice cultivation, has increased annually, both in terms of cultivated land and production. Agricultural areas expanded from 26% to 31% of land area between 1997 and 2007 (Bansok et al., 2011).

Rice in Cambodia is grown in four major systems: rain-fed lowland rice, rain-fed upland rice, floating and recession rice, and dry season irrigated rice (Thomas et al., 2013). Irrigation development

Figure 3. Dominant land use across Southeast Asia based on 2011 MODIS data



is the most important factor to increasing rice productivity. Rice is also an important export commodity and accounted for more than 10% of the country's total export in 2007 (Yu and Diao, 2011). Bansok et al. (2011) reported that in 2010, Cambodia had roughly 2.79 million ha of cultivated land with 2.39 million ha under wet season rice cultivation. Average yield of wet season rice is 2.75 tons per ha compared to about 4.20 tons per ha for dry season rice.

Diversification of rain-fed lowland rice is one of the primary intensification processes underway in Cambodia. This includes double cropping through irrigation to support a second rice crop (rice-rice), or another crop such as maize, mung bean, or soybean (Seng et al., 2008). Other major agricultural crops include maize, cassava, soybean, peanuts and rubber. Fisheries contributed 25% to the agricultural GDP in 2011, out of which inland fisheries contributed 83% of the total fish production (KOC, 2012). Aquaculture systems are of growing importance as well with the potential to be expanded to the extent that investments are made in farmer capacity building, market linkages, and infrastructure for processing (Tiet Khan, 2013). Conversely, forest production has declined from 9% to 6% of the agricultural sector (MAFF 2011), and is not expected to increase due to national policies. Enforcement of forest resource conservation is an on-going challenge. Fishery and forestry resources are important coping mechanisms for resilience in the face of extreme weather and market shocks and integral to livelihood strategies of poor rural households.

Most of the cultivated area in Cambodia is rain fed with roughly 9% of the total cultivated area under irrigation (FAO, 2013b). Since 80-90% of the annual precipitation occurs during the wet season, water is often limited during the dry season. Flooding, particularly from the Mekong and the Tonle

Sap, has historically been more closely associated with crop failures than drought. Flooding tends to cause on average a 70% loss in yield; drought, a 20% loss (ADB 2009). In 2009, roughly 2% of the rice crop was damaged due to inadequate rainfall in the wet season, thus intermittent dry spells are also an occasional problem (Sophal, 2009).

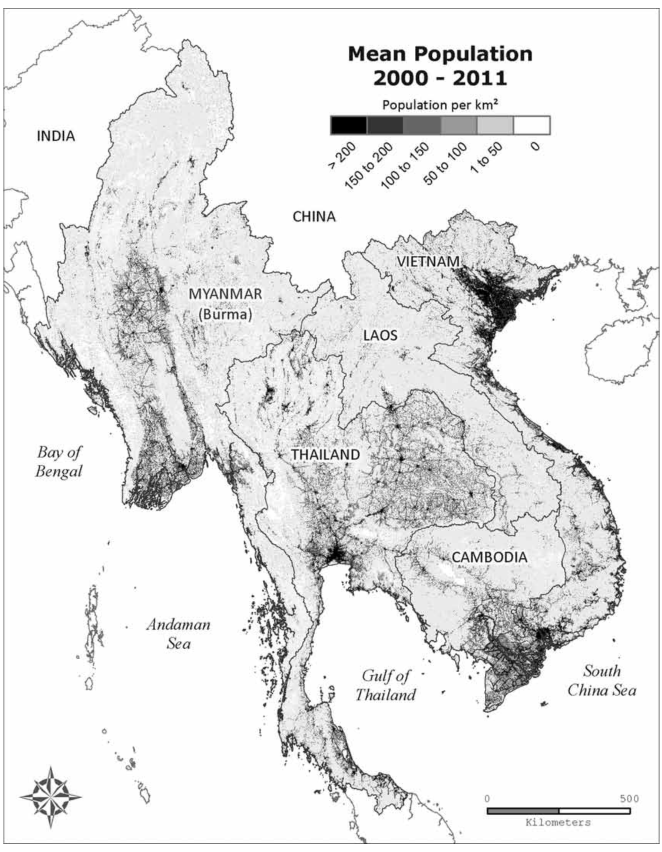
POPULATION

The population of Cambodia is dynamic, and although smaller than its neighbors, Cambodia is characterized by important movements among locations and across economic sectors. The rural population (Figure 4) is concentrated along the highly productive plains along the Tonle Sap Lake, northwest of Phnom Penh (Heinonen, 2006). In 2013, the total population was estimated to be 15,205,539 with an annual growth rate of 1.7% (CIA, 2014). This moderate growth rate is despite a relatively high birth rate (approximately 24.9 per 1,000) compared to the low death rate (7.9 per 1,000).

FERTILITY

Cambodia had high fertility rates until the recent past when it declined rapidly from 4.9 births/woman to its current estimated 2.7 births/woman. The decline in the fertility rate reflects both rapid economic and social changes, and the availability and usage of contraceptives, now used by over 50% of the population (CIA, 2014). The recent changes in fertility must be understood against the

Figure 4. Southeast Asia population density (people/km2; average from 2000 to 2011) (Data source: LandScan 2013)



historical backdrop of the civil war in the 1970s, however, which has shaped current trends. The 1970s were a tumultuous decade in Cambodian history. Violent conflicts occurred in the first half of the decade, followed by the Khmer Rouge government in the latter half (1975-1979) (de Walque, 2005; Neupert & Prum, 2005). Under this regime, an estimated 2 million people –approximately 20% of the population – died as a result of political executions, starvation and illness (UNFPA, 2012; de Walque, 2005; Neupert & Prum, 2005). Under the Khmer Rouge regime, the cities were essentially evacuated and citizens were forced to live and work on collective farms (UNFPA, 2012; de Walque, 2005).

Current population statistics and demographic trends have important implications for Cambodia's economy. Cambodia has a young population (70% under the age of thirty-five (FTF, 2013)) and it will remain in this state for several years (the so-called "Goldilocks Moment" with a high percentage of population of working age). After the 1970s, the population grew rapidly until around the year 2000 when fertility rates declined to their current level of slightly higher than replacement. The national net international migration rate is -0.3 per 1,000 (CIA, 2014). The population of Cambodia will continue to increase in the next 30 or more years even with low fertility rates due to the inherent momentum of large numbers of people reaching the age of childbearing. Although the population will continue to grow, the rate of increase is expected to continue to decline to around 0.2 in 2045 (UN, 2013).

MIGRATION

In recent years, Cambodia's urban and rural populations have been growing, but at different rates. The result is a shift in the location of much the population. While historically the population had been dominantly rural, in the 1970's the urban population began to steadily grow at a faster rate than the rural population. The cause of the differential growth rates has been migration from rural to urban areas. Heinonen (2006) estimates that nearly 35% of the country's 13 million people have migrated at least once in their lifetime. According to the U.N. (2013), the rural population growth rate will continue to experience a decline, and by 2015 the rural population was expected to begin shrinking. The urban population, on the other hand, is expected to continue to grow in the range of 1% to 2% annually. Nevertheless, the actual number of people in rural areas is expected to remain larger than in urban areas until sometime after 2045.

The implications for Cambodia's agricultural sector directly related to these population shifts include:

1. Continued, if slowing, population growth in rural areas in the near future;
2. By 2020, the rural population size should level off and then start to shrink due to out-migration and low fertility rates;
3. Once the rural population starts to shrink, it will become increasingly older and fewer young people will be available to farm. Labor will need to be replaced by mechanization and other labor saving strategies. Farms may consolidate;
4. Meanwhile the urban population will continue to grow steadily in the medium-term, at least until the middle of the 21st century. This population will need an increasingly large food supply.

GENDER AND MIGRATION

Migration in Cambodia is a highly gendered process. In the origin communities, the departure of men and women is forcing changes in the household divisions of labor (Kelly, 2011). The occupations that migrants seek are gender segregated as well (UNFPA, 2012; Kelly, 2001; Piper, 2008). The common pattern of internal migration is that men leave to seek agricultural work in another rural area, while women leave for urban areas to work in garment factories. Women routinely earn less than men and women with children are shown to be less likely to migrate (UNFPA, 2012; Turunen, et al., 2009).

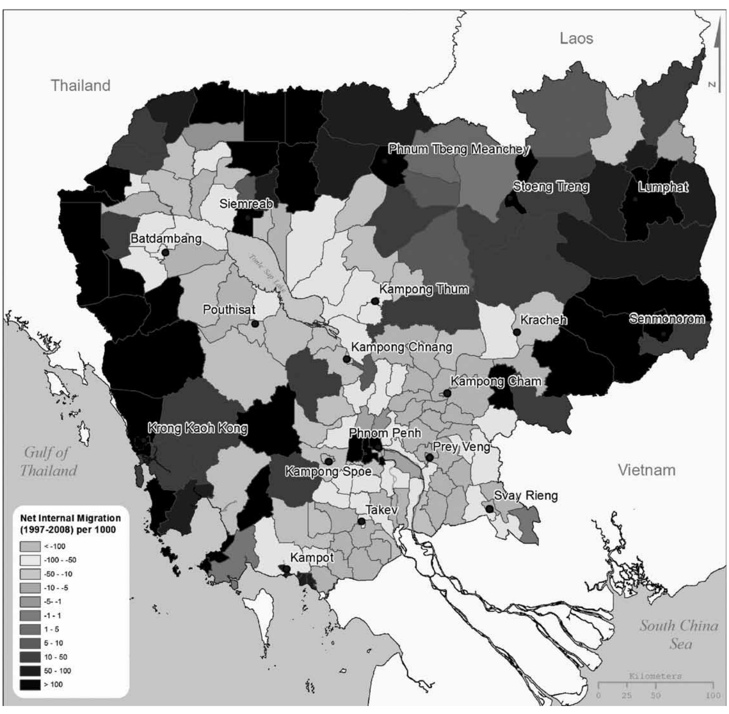
According to Cambodia's Ministry of Planning Report of the Cambodian Rural Urban Migration Project, "While female migrants make less money, they are more likely to remit to their village of origin, remit on a more regular basis and remit a larger percent of their total earnings" (2012, p. 91).

Gender inequity is rooted in Cambodian society and creates barriers to women's participation in the rural economy. It constrains women's opportunities, such as reducing their access to resources (such as land), control of credit, and ability to ensure that agricultural inputs meet their immediate needs (Solar, 2010). However, Lina (2012) found that women who do earn more money than their husbands are more likely to play an active role in deciding how their earnings are spent. Additionally, approximately 45% of women said they were the sole decision-maker about their own health care, while decisions about major household purchases were usually made jointly by the husband and wife (Lina, 2012). Investments are needed that will build the capacity of women, including, "Improving women's access to land, control of credit, and ensuring that agricultural inputs meet their immediate needs (Solar, 2010, p. 2)."

RURAL AND URBAN PATTERNS

Net migration from 1997 to 2008 by province is depicted in Figure 5. Phnom Penh City is a major destination for migrants. Rural areas outside of the central lowlands were also shown to be important destinations. Heinonen (2006) found that some of the highest negative net-migration rates are occurring in the provinces surrounding Tonle Sap Lake. This region is where the USAID program Feed the Future is focusing its initiatives in Cambodia, specifically the provinces of Battambang, Siem Reap, Kampong Thom, and Pursat. This region has the country's highest poverty rate (45%) as well as approximately one-third of Cambodia's food-insecure households (FTF, 2012). The Tonle

Figure 5. Net internal migration rate, 1997-2008 (number of net migrants per 1,000 population). Dark colors indicate zones of in-migration and light colors indicate zones of out-migration. Data source: Cambodia Demographic Census 2008 (from Atlas of Cambodia 2013).



Sap region also has the highest concentration of child stunting and under-nutrition. The poverty and high population densities in the Lake region would be strong push factors for out-migration.

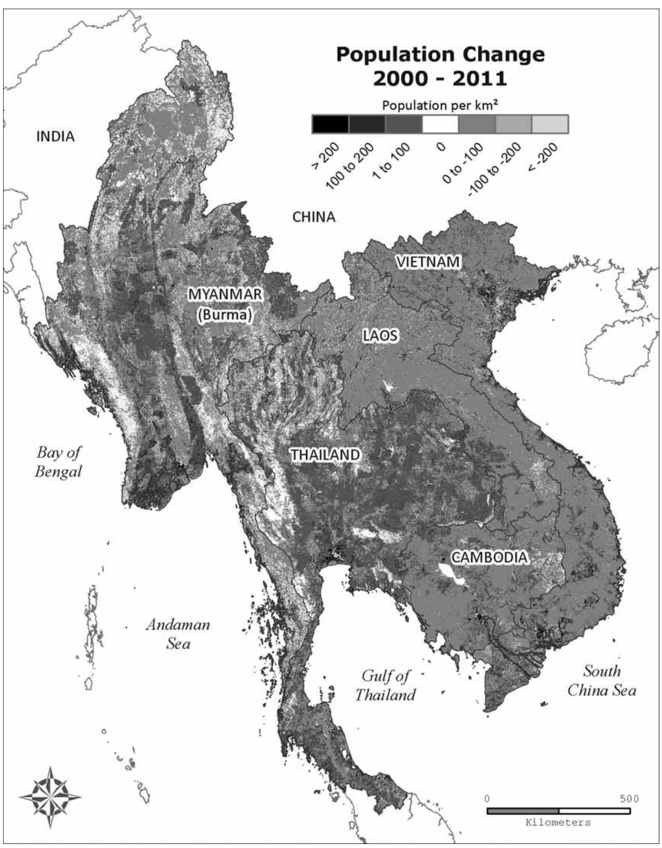
Another view of movement of the rural population is shown in Figure 6, which illustrates changes in population densities between 2000 and 2011 in Southeast Asia. Similar to previous figures, it reveals a net loss of population in the central Lake region of Cambodia. In Cambodia, much of the rural-rural migration is seasonal and driven by people looking for agricultural work, fishing, and construction work (Turunen, et al., 2009). It is expected that the Tonle Sap region's annual population growth rate of 4.8% will worsen the shortage of food and arable land, as well as contribute to the high migration rate (4%) that it has experienced over the past six years. Although rural out-migration may bring in needed income, it is also leading to a loss of labor and agricultural knowledge (UNFPA, 2012).

Cambodian farmers face numerous hardships that compound the effects of out-migration, and reinforce the drivers to leave rural areas. One of the greatest challenges is that only about 20% of the country's land is arable. Agriculture remains primarily un-mechanized and the lack of infrastructure limits transportation between villages and markets (UNFPA, 2012; FAO, 2011; Turunen, et al., 2009).

Implications of these trends of rural-rural migration for Cambodia include:

1. In the origin areas, the loss of young men and women available to conduct farm labor;
2. A possible reinforcement of poverty in the poor households whose young members have left (especially the departure of young men, who tend to send fewer remittances);
3. An increase in wellbeing of families receiving remittances with potential spillover effects improving the economy of the village;

Figure 6. Change in population density, 2000 to 2011 (Data source: LandScan 2013)



4. In the origin areas, an eventual loss of local agricultural knowledge base;
5. A leveling off then shrinkage of rural population numbers in Cambodia;
6. Redistribution of population from the central plains around Tonle Sap Lake towards cities and towards the peripheral provinces;
7. Conversion of land cover from forest to cultivation in the peripheral provinces.

As of 2012, only 20% of Cambodia's total population was living in urban areas. This urbanization fraction is extremely low. It lags other countries in mainland Southeast Asia (31% in 2010). Nevertheless, like other countries in the region, Cambodia's urban population has increased rapidly in recent years, mostly due to rural-urban migration. While the total population of Cambodia experienced a doubling in the post-civil war period, its urban population increased almost five fold. According to a survey conducted by the Ministry of Planning in 2012, the rural area is losing 4% of its population annually due to net out-migration. Half of this rural out-migration population is flowing to the capital city, 30% is leaving Cambodia going to other countries, a small portion (13%) is going to other rural areas, and even a smaller portion (6%) is going between urban areas. The urbanization fraction jumped from 9% in 1980 to 20% in 2010. Fifty-four percent of all its urban population is concentrated in the capital city, Phnom Penh. The rest of Cambodia's urban population is scattered in other cities, which hardly compare with the scale of Phnom Penh (World Bank, 2013).

Out-migration has had both positive and negative impacts on origin villages. It helped to improve the standard of living of the migrant's household, increased the money coming into village, increased the employment of villagers, and improved the human resources of the village. On the other hand, it had negative impacts including the loss of labor, decreased production, and loss of population. While migrants' remittances to their families in places of origins are helpful, the impact has been assessed as being minor because the average remittance is only about $23 USD per month (UNFPA, 2012).

The large inflow of migrants to cities, especially to Phnom Penh, has left a remarkable impact demographically and spatially. The capital city has experienced rapid population growth and a drastic transformation of its population composition. Phnom Penh more than doubled its population in one decade; it grew from 567,860 in 1998 to 1,236,600 in 2008. Over 80% of that growth was due to net-migration (UNFPA, 2012).

CLIMATE TRENDS

Cambodia has a monsoon climate with two seasons: a rainy season from May to October and a dry season from November to April. Average annual precipitation ranges from 900 mm in the central regions to 4,000 mm in some coastal regions (Hijmans et al., 2005). The dominant agricultural production systems across the country are determined largely by precipitation zones, which vary from the two high rainfall areas (>3,000 mm along the coast and along the tip of the Northeast) to the relatively dry northern and southern belts on the western side of the country with a pronounced unimodal rainfall pattern of 900 to 1,400 mm (Thomas et al., 2013).

Major climate hazards in Cambodia are floods, droughts, windstorms, seawater intrusion, and high tides (MOE, 2006). Cambodia is a disaster-prone country where floods and droughts occur on a seasonal basis and are frequently cited as the major contributors of poverty (The World Bank, 2011; MOE, 2006). Annually, all Cambodian provinces suffer from at least two flooding events, some as many as four. Droughts have historically also had severe impacts on agriculture, and even more so now that the floods and windstorms have extended into previously unaffected areas. Paradoxically, sometimes flooding and droughts occur in the country in the same year. Rural households were surveyed by the RCG in 2004, and the findings confirm that both floods and droughts are ongoing, and are severe constraints to food production (Thomas, 2013).

The mean annual temperature in Cambodia has increased by 0.8°C since 1960 but no significant change in precipitation patterns has been observed during the same period (McSweeney et al., 2008).

The Intergovernmental Panel on Climate Change (IPCC) predicted a temperature rise of 2.5°C in Southeast Asia by the end of this century (Christensen, 2007), which is in agreement with the projections made by Cambodia's Initial National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (Figure 7).

This national study examined the A2 and B1 scenarios and projected temperature increase up to 0.60°C by 2025, 1.00°C by 2050 and 2.50°C by 2100 (MOE, 2002). Cambodia's Initial National Communication to the UNFCCC, IPCC report and the United Nations Development Programme (UNDP) Climate Change Country Profile for Cambodia, all project an increase in precipitation over the country in the future. IPCC projects a median increase of 7% over Southeast Asia by the end of the century (MOE, 2002; Christensen, 2007; McSweeney et al., 2008). Furthermore, McSweeney et al. (2008) projected an increase in the amount and intensity of precipitation during the wet season and a decrease in dry season over Cambodia. One significant challenge for assessing or modeling climate change in Cambodia is the lack of data. There are only ten Global Summary of the Day (GSOD) sites and only one World Meteorological Organization (WMO) site on the coast, and that is actually in Thailand. The lack of quality weather data and clear reporting makes detection of trends very difficult and mostly reliant on remotely sensed data.

Mekong River Impacts

A range of future climate change scenarios are predicted, depending on the Global Circulation Model (GCM) used. Four out of five models surveyed by Thomas et al. (2013) predicted increased rainfall, although they are split regarding the extent to which the rainfall will increase within the rainy season, or over the entire year. Overall projections for climate change impacts on rainfall are complex in Cambodia, and often disagree, although incidences of higher rainfall for at least some of the country are a general feature. As a result of climate change, the dry season in the Mekong Basin is projected by some studies to be drier with an increased length and the wet season is projected to have a later onset, shorter duration and increased intensity of precipitation (Figure 8) (Snidvongs et al., 2003; TKK and SEA START RC, 2009). Length of the rainy season is projected to shorten by as

Figure 7. IPCC AR5 ensemble mean (75th percentile) warming for SE Asia for the RCP4.5 scenario

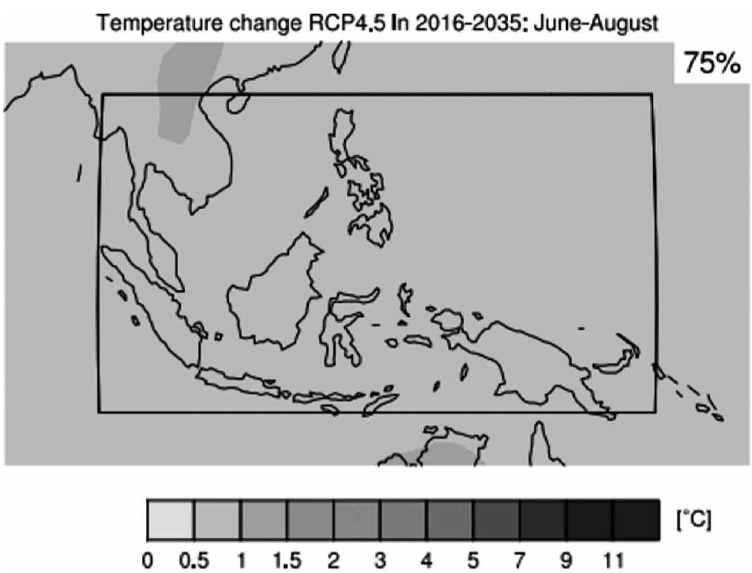
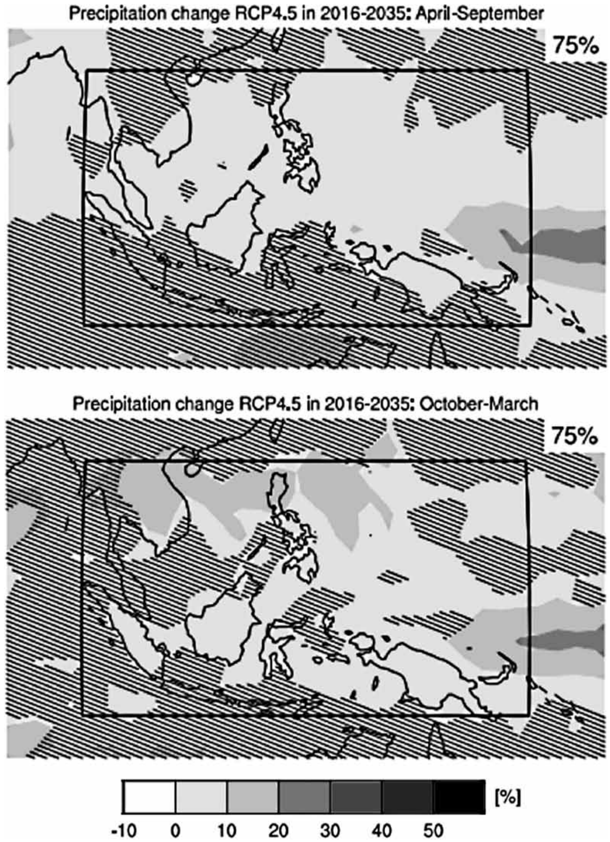


Figure 8. Seasonal differences in predicted precipitation



much as one to two months under the doubling CO_2 scenario (Snidvongs et al., 2003). As a result, the maximum flow of Mekong River in the basin is projected to increase by 35% during 2010-2038 and 41% in 2070-2099 and the minimum flow is projected to decrease by up to 17% in 2010-2038 and 24% in 2070-2099 (Hoanh et al., 2004). As maximum and minimum flows occur in wet and dry seasons, respectively, there could be increased risk of flooding during wet seasons and further shortage of water during dry season.

Cambodia, with a coastal zone in the southwestern part of the country, is also vulnerable to sea-level rise. A one-meter rise in sea level has been estimated to inundate 0.4% of Koh Kong Province and 56% of Koh Kong town (MOE, 2002). Apart from direct inundation, rise in sea level also poses risk of salinization of the freshwater resources, especially during the dry season. With an increase in temperature, annual potential evaporation rate has been predicted to increase by 2% by 2030 compared to 2000 (Eastham et al., 2008). Moreover, the potential evapotranspiration rate during February-June is predicted to be 50% more than the rest of the year, further increasing water stress during the dry season (Eastham et al., 2008). There are limited studies on the impacts of climate change on groundwater in Cambodia. However, sea level rise and subsequent saltwater intrusion pose risks to groundwater resources in the coastal areas in the southeastern part of the country. Salinization of the groundwater resources is expected to increase when the water level in the rivers and groundwater recharge decrease during the dry season.

CLIMATE CHANGE IMPLICATIONS

Climate change presents myriad challenges and stresses for impoverished Cambodians. The main impacts include water scarcity, crop failures, and food shortages (Solar, 2010). The ecosystem of the Tonle Sap region is already showing signs of developing an enhanced cycle of flooding and droughts. This along with soil degradation is making agricultural production in the region less profitable. An example of this is in Battambang where drought has caused major damage to the rice crops of a third of the farmers (Turunen et al., 2009). The full environmental costs of climate change in Cambodia, including high market volatility for agricultural products, must be examined with consideration for the long-term sustainability of the rice production systems. The Food and Agricultural Organization recommends adopting crop rotation, diversification and other practices to sustain efforts towards improving food security (FAO, 2011; FAO/WFP, 2012). Furthermore, this survey found that food deprivation is more prevalent among rural than urban populations. Most of the rural population was said to be, "Landless or land-poor, rely on agriculture alone, have limited cash-earning employment opportunities, and typically depend on seasonal casual wage labor (p. 14)." It was also determined that food deprivation is more prevalent in female-headed than male-headed households. Rice, the staple food in Cambodia, plays a significant role in food security for households. Protein consumption is primarily from fish – ranging from 40% - 90% of all animal protein consumed in fishing dependent communities (Turunen et al., 2009). Turunen et al. (2009) found that people in Cambodia are more often experiencing "hungry months" during which there are shortages of food. Migration has been an important household strategy to increase food security through diversifying income opportunities. Additionally, improved infrastructure, such as better roads, are needed to allow for, "more diverse livelihood possibilities and higher income levels" in response to these climate change implications (Turunen, et al., 2009, p. 27). These factors affect the health and wellbeing of the population. The Cambodia Socio-Economic Survey of 2004 cites, "Household food insecurity, undernourishment, and child malnutrition (p. 14)" as significant concerns.

Climate Vulnerability

Vulnerability arises from Cambodian's excessive reliance on agriculture, animal husbandry, and fisheries, which largely depend on the availability of natural resources, and thus are inherently susceptible to climate extremes (Solar, 2010). With 20.5% of the population living below the national poverty line (The World Bank, 2011), Cambodia is one of the poorest countries in Southeast Asia. This large impoverished population is considered the most vulnerable to climate change as they lack minimum financial, technical and human resources to cope with these changes (Erikson et al., 2007). Thus, low adaptive capacity along with higher dependency on agriculture make Cambodia one of the most vulnerable countries to climate change and variability (Thomas et al., 2013, Mendoza et al. 2014, Dany et al. 2015). Inadequate infrastructure and limited institutional capacity have only served to further exacerbate vulnerability (The World Bank, 2011).

Highly uneven temporal distributions of rainfall combined with limited water storage capacity and basic irrigation system development make the agricultural water resources in the country acutely vulnerable to climate change. Water shortages are already a constraint for agricultural production in Cambodia and have led to conflicts among farmers (Nang et al., 2011). The Cambodian National Adaptation Programme of Action to Climate Change (NAPA) conducted a survey across 17 provinces and reported that 81% of the population has already suffered from water shortage for agricultural use while 54% suffered from water shortage for household water use (MOE, 2006). With predicted increases in rainfall anomalies along with potential sea level rise and increased evapotranspiration, available water resources in the country will be strained under climate change, threatening food security. Other key issues in the water resource sector in Cambodia include lack of integration of hydrological features in climate and weather forecasting, weak regulatory framework in water resources management, and low efficiency of the existing irrigation systems (KOC, 2012).

Gendered Responses to Climate Change

At the household and individual levels, vulnerability to climate change are further shaped by gender differences in: (1) roles and responsibilities; and (2) in access to and control over productive assets (for instance land, water rights). According to the UNIFEM et al., (2004), due to the lack of easy access to clean water, women and girls spend hours of their day (1-2 hours during the rainy season and up to 3 hours in the dry season) collecting water for household needs. This responsibility represents a drain on women's time and increases the opportunity costs of sending girls to school and also for employment in income generating activities. Solar (2010) also observes that women have to perform multiple tasks such as family care giving, fetching water, cultivating land, allocating resources for food and other uses, and have less time to acquire skills and knowledge required for climate change adaptation, making them the most vulnerable group of people in the country. Gender differences in roles and responsibilities also create gendered priorities in the delivery of water services at the community level (UNIFEM et al, 2004). Women want more convenient access to safe water for drinking, cooking and bathing purposes, and they did not want to spend much time accessing it for their daily needs. Time spent retrieving water did not seem to be a major concern for men. Instead, men asked for irrigation systems for crops but not for household farming systems (UNIFEM et al, 2004).

Gender inequalities in access to and control over resources and services and the predominance of women in agriculture also make women more vulnerable to climate change than men. Women make up more than half of the agricultural workforce in Cambodia (UNIFEM et al., 2004). However, according to Beresford et al, (2003) increasing landlessness and near-landlessness, combined with diminishing access to common property resources, reflects that an increasing number of people, especially women, in rural households will remain without any productive resources except their own labor, thereby limiting their potential to contribute to improved productivity, greater food security and reduced poverty. Secure land tenure has been identified as a critical development and gender issue, and women, especially women-headed households, are more likely to be landless or have significantly smaller plots of land. Female farmers in particular, lack access to high quality inputs, credit or information on farming techniques and markets, agricultural extension services, market information, and financial services (UNIFEM et al., 2004). Given the critical role of assets in determining climate change adaptive capacities, such gender disparities in assets certainly have implications for how men and women adapt to climate change.

Adaptations

Major adaptation challenges in the water sector in Cambodia are protection from floods during the wet season and ensuring water resources availability during the dry season. Digging wells for household water, construction of ponds and reservoir for water storages, construction of canals for irrigation and building dikes or water control structures are among the suggested measures for adaptation to drought and floods (Thomas et al., 2013). Cambodia's NAPA has identified rehabilitation of dams, reservoirs, flood protection dikes, canals, and waterways; construction of water gates and culverts; development of small-scale aquaculture ponds; and development and improvement of community irrigation systems as adaptation measures to climate change. Construction and rehabilitation of dams and reservoirs are crucial for reducing the peak flow during the flood season and supplying water for the dry season. With the gender differences in priorities for water resources as well as in adaptive capacities, the appropriate adaptive measure(s) should be those that have a strong potential for responding to the priority needs of rural household domestic use as well as food production.

Market Adjustments

Farmers and rural communities in Southeast Asia face rapidly changing market contexts, which necessitate close attention to enhancing adaptation capacity at local levels. A critical role for participatory action research and education was a key finding in a quantitative assessment of agricultural development program effectiveness for thousands of cassava farmers in China, Vietnam and Thailand (Dalton et al., 2011). Agroforestry practices were widely adopted and led to substantial production gains, particularly among farmers engaged intensively in participatory, experiential learning and adaptation of technologies. Another review of farmer adoption, assessing the 'System of Rice Intensification' in Cambodia and the region, found that adaptation of this intensified system to local context was essential, and indeed the technologies were less important than participatory engagement with farmers to support innovation (Ly et al., 2012). Crop diversification has shown potential in Cambodia as part of sustainable intensification, notably the double cropping of mungbean or soybean after rain fed rice (Seng, et al 2008). Mechanical planting of rice and no-till planting other crops on beds as a means to enhance water and soil management has also been promoted, although there are a wide range of technical, infrastructural and social challenges that remain to be addressed (Balasubramanian, et al., 2003).

Cultivar Selection

A growing consensus is that improvements in crop genetics need to be developed in conjunction with farmers and management systems, to be applicable across a broad range of environments as part of integrated farming solutions (Glover, 2013). At the same time, genetic improvements in rice specifically targeted to address flooding has led to the development of submergence-tolerant types of rice that have proven ability to reduce yield variability and survive extended inundation (Dar et al., 2013; Fukao and Bailey-Serres, 2008). Recently, a combination of flood, drought and saline resistant types of rice have been developed that could provide more options for farmers coping with a changing climate and degraded soils. The International Institute for Rice, in close collaboration with national programs across South East Asia, recently released new rice varieties with this combination of traits in 10 countries, including Cambodia (Ison, 2014).

Governance

Cambodia's NAPA has highlighted limited awareness of climate change issues; inadequate technical, financial, and institutional capacity of the concerned agencies, and inadequate integration of climate change issues into national policies and programs as the major barriers in implementing adaptation measures (MOE, 2005; 2006). Thomas et al. (2013) pointed out that farmers are aware of the adaptation measures but lack financial resources to implement them. The majority of rural credit businesses, including crop production credits, in Cambodia are controlled by informal sectors, which charge excessive interest rates on loans (Bansok et al., 2011). Moreover, the terms and conditions of these loans are not conducive to the poor borrowers. Women (especially female headed households), face specific challenges with respect to access to financial resources. According to UNIFEM et al., (2004), women have limited access to credit and credit providers reach only 20% of all households. Furthermore, while women make up a high proportion of membership in credit schemes, they tend to be excluded from the decision-making processes and receive smaller amounts of credit. Easier access to credit would enable farmers to establish irrigation systems and purchase farm inputs such as improved crop varieties and fertilizers, which in turn, increase the farmers' resilience against extreme events. Overall, disparities between men and women in resources, decision-making power, and basic social wellbeing, coupled with widespread poverty, stand as significant constraints to sustainable economic and social development.

AN AGRICULTURAL INNOVATION PIPELINE FOR CAMBODIA: CLIMATE CHANGE AND PRESSURES ON RESOURCES

In addition to the adaptations previously mentioned, an innovation pipeline is presented in the following section, organized as a list of action items in two sections: 1) research where investments could be made with a high likelihood of success and measurable impact, and 2) research questions and issues that are less likely to be successfully resolved, but given changing conditions or substantial creative insight might have meaningful impact. This list is ordered by precedence and potential impact.

Innovation Pipeline

1. Action items worthy of near term investment and development research:
   a. In Cambodia, the optimization of water resources is critical during both wet and dry seasons. Agricultural management practices and conservation measures, including no-till planting for diversified production resilient to variable weather, the development of new rice varieties, and improved dry land rice cultivation, are best bets. New rice varieties that are flood-tolerant show tremendous potential in a flood prone system; and drought and saline tolerant genetics are also under development for rice;
   b. Small-scale water storage facilities for supplementary irrigation and community-level innovations to enhance management, facilities and equitable access to groundwater for household and irrigation use will improve resilience and adaptation to climate stresses. Intensification and diversification of farming is needed; dry season rice yields are higher than rainy season yields and could be expanded via irrigation (MAFF Annual Development Report for 2010-2011);
   c. More than most other countries in South East Asia, Cambodia suffers from an acute shortage of weather and climate data collecting systems. Coordinated community based weather instrumentation and reporting will improve base volumes and representativeness of climate data and improve local responsiveness to weather trends. Here "coordinated" refers to a system where different communities share skills, data formats, installation, and storage procedures so that no duplication occurs and that monitoring is effective;
   d. Detailed climate projections, both statistical or RCM downscaling, would be modestly helpful for identifying area-based adaptation approaches;
2. Action items worthy of investment if conditions change or new science emerges:
   a. Cambodia has minimal irrigation infrastructure (FAO, 2013b). Enhanced infrastructure and market linkages for aquaculture as part of an integrated farming system is clearly lacking (Tiet Khan, 2013);
   b. Reliance on rainfall for agricultural production has increased the risk of food insecurity. Management systems for resilient management of both floods and droughts are seriously underdeveloped (KOC, 2012);
   c. A government initiated land distribution program, in which state land is provided to poor and landless families (GIZ, 2012) might ameliorate land pressures. The methods used to identify vacant land, and subsequent allocation, represent an important problem for land use land cover change (LULCC) science and for adaptation to climate change;
   d. Forested regions of Cambodia are under public ownership and managed by the Cambodian Forestry Administration. However, falling standards of governance and weakly implemented forestry policy contributed to high rates of deforestation and forest degradation (Broadhead and Izquierdo, 2010).

CONCLUSION

Climate change and variability presents myriad challenges to agricultural production and food security in Cambodia and the vulnerability is only projected to increase in the future. Reliance on natural resources, minimal infrastructure for regulating soil and water use in agriculture, and limited investment in farmer education and adaptive capacity, have made Cambodia particularly vulnerable to climate change in a regional context (Solar, 2010). Major impacts of climate change across sectors are expected, despite that ensemble GCMs vary in predictions related to onset, duration, and intensity of precipitation. Further, it is not known the extent to which seawater intrusion and decreased crop water availability will impact production. Major identified adaptation measures are either related to controlling flood and sea level rise or increasing water availability during dry seasons (MOE, 2006; Thomas et al., 2013). Lack of financial resources to implement adaptation measures is the major constraint in increasing climate change resilience (MOE, 2006; The World Bank, 2011). There are a number of exciting new developments in genetic options for the most important crop in Cambodia, notably flood-resistant rice varieties (Zhao et al. 2014), as well as drought and saline adapted genetics in the pipeline. Investments in participatory action research and extension are urgently required to support farmers in evaluating novel varieties, as part of an effort to enhance capacity to regulate water, manage soils and grow appropriate crop genetics for sustained production.

Cambodian society is largely patriarchal and hierarchical, with strong traditional norms and notions of power and status conditioning social and gender relations (UNIFEM et al., 2004). Gender is a critical factor that influences how men and women experience climate change pressures on their ability to adapt/respond and to develop resilient agricultural production systems. Recent advances in rice genetics have provided a unique opportunity for participatory research and extension of flood-tolerant types of rice varieties. These efforts have been particularly effective at engaging women farmers in SE Asia, and are highly promising for the Cambodia context. As climate change remains one of the most significant drivers of population scale risks in vulnerability, resilience, and adaptation, continuing to identify actionable research is critical in mitigating future food insecurity issues directly linked to changing climate. In this way, improvements in food security for highly vulnerable populations like Cambodia may be considered in an effort to lessen climate changes' potential impact.

ACKNOWLEDGMENT

This work was supported in part by the NASA Land-Cover and Land-Use Change Program (NNX15AD51G), the United States Agency for International Development (AID-OAA-A-13-00006), NIFA, and MSU AgBioResearch. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the US Agency for International Development or the US Government. We also would like to thank Mr. Brad Peter and Mr. Mark Devisser for cartographic assistance.

REFERENCES

Adger, N. (1999). Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Development*, *2*, 249–269.

Adger, W. N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography*, *24*(3), 347–364. doi:10.1191/030913200701540465

Arias, M. E., Cochrane, T. A., & Elliott, V. (2014). Modelling future changes of habitat and fauna in the Tonle Sap wetland of the Mekong. *Environmental Conservation*, *41*(02), 165–175. doi:10.1017/S0376892913000283

Asian Development Bank (ADB). (2000). *Environments in Transition – Cambodia, Lao PDR, Thailand, Vietnam*. Manila: ADB.

Asian Development Bank (ADB). (2013, August 26-30). Country Paper on Climate Change Mitigation in Agriculture in Cambodia. *Proceedings of the Workshop on Developing Farming Systems for Climate Change Mitigation*, Colombo, Sri Lanka.

Balasubramanian, V. J. K. Ladha, R.K. Gupta, R.K. Naresh, R.S. Mehla, Singh, B., & Singh, Y. (2003). Technology options for rice in the rice-wheat system in Southeast Asia. In Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts (pp. 115-147). American Society of Agronomy.

Bansok, R., Phirun, N., & Chhun, C. (2011, December). *Agricultural Development and Climate Change: The Case of Cambodia.* CDRI Working Paper Series No. 65. Retrieved from http://khmerstudies.org/wp-content/uploads/2013/06/12.-Climate-Change-CDRI.pdf

Bates, Bryson, et al. (2008). Intergovernmental Panel on Climate Change. *Climate change and water technical paper of the Intergovernmental Panel on Climate Change*.

Bates, B. C., Kundzewicz, Z. W., Wu, S., & Palutikof, J. P. (Eds.). (2008). Climate Change and Water (Technical Paper of the Intergovernmental Panel on Climate Change). Retrieved from https://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf

Beresford, M. (2003). The Macroeconomics of Poverty Reduction in Cambodia. United Nations Development Programme, Phnom Penh.

Broadhead, J., & Izquierdo, R. (2010). *Assessment of land use, forest policy and governance in Cambodia* (Working Paper 91). Cambodia Food and Agriculture Organisation Regional Office for Asia and the Pacific Country Representation.

Cambodia Socio-Economic Survey. (2003/04). Food insecurity assessment in Cambodia. National Institute of Statistics, Ministry of Planning. Phnom Penh: Cambodia.

Central Intelligence Agency (CIA). 2014. The World FactBook. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., & Whetton, P. et al. (2007). *Regional climate projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Clausen, T. J. (2009). *Technical Annex on Integrated Water Resource Management*. ADB and Ministry of Water Resources and Meteorology.

Dalton, T., Lilja, N., Johnson, N., & Howeler, R. (2011). Farmer participatory research and soil conservation in Southeast Asia cassava systems. *World Development*, *39*, 2176–2186.

Dany, V., Bajracharya, B., Lebel, L., Regan, M., & Taplin, R. (2015). Narrowing gaps between research and policy development in climate change adaptation work in the water resources and agriculture sectors of Cambodia. *Climate Policy*.

Dar, M. H., de Janvry, A., Emerick, K., Raitzer, D., & Sadoulet, E. (2013). Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefitting socially disadvantaged groups.Error! Hyperlink reference not valid. *Scientific Reports*, *3*, 3315. doi:10.1038/srep03315 PMID:24263095

De Walque, D. (2005). Selective mortality during the Khmer Rouge period in Cambodia. *Population and Development Review*, *31*(2), 351–368. doi:10.1111/j.1728-4457.2005.00069.x

De Walque, D. (2006). The socio-demographic legacy of the Khmer Rouge period in Cambodia. *Population Studies*, *60*(2), 223–231. doi:10.1080/00324720600684767 PMID:16754253

Department of Climate Change (DCC). (2010). *Enabling activities for the preparation of the Kingdom of Cambodia's Second National*.

Eastham, J., Mpelasoka, F., Mainuddin, M., Ticehurst, C., Dyce, P., Hodgson, G., ... & Kirby, M. (2008). *Mekong river basin water resources assessment: Impacts of climate change*.

Eriksen, S. E., Klein, R. J., Ulsrud, K., Næss, L. O., & O'Brien, K. (2007). Climate change adaptation and poverty reduction: Key interactions and critical measures (GECHS Report).

FAO/WFP. (2012). FAO/WFP Crop and food security update mission to Cambodia. Retrieved from http://www.fao.org/giews/ /

Feed the Future (FTF). (2012). Cambodia Factsheet. Retrieved from feedthefuture.gov/sites/default/files/country/strategies/files/ftf_factsheet_cambodia_jul2012.pdf

Feed the Future (FTF). (2013). Country profile: Cambodia. Retrieved from http://www.feedthefuture.gov/country/cambodia

FitzGerald, E. V. K. (1994). The economic dimension of social development and the peace process in Cambodia. In P. Utting (Ed.), *Between hope and insecurity: the social consequences of the Cambodian peace process*. Geneva: UNRISD.

Food and Agricultural Organization of the United Nations (FAO). (2005). *Global Forest Resources Assessment 2005 - Progress Towards Sustainable Forest Management*.

Food and Agriculture Organization of the United Nations (FAO). (2011). Cambodia and FAO achievements and success stories.

Food and Agriculture Organization of the United Nations (FAO). (2011). FAOSTAT. Retrieved from faostat.fao.org

Food and Agriculture Organization of the United Nations (FAO). (2013a). *FAO statistical yearbook 2013: World food and agriculture*.

Food and Agriculture Organization of the United Nations (FAO). (2013b). *Aquastat online database*.

Fukao, T., & Bailey-Serres, J. (2008). Submergence tolerance conferred by Sub1A is mediated by SLR1 and SLRL1 restriction of gibberellin responses in rice. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(43), 16814–16819. doi:10.1073/pnas.0807821105 PMID:18936491

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (2012). Land Use Planning: Concept, Tools and Applications.

Glover, D. (2013). *Of yield gaps and yield ceilings: Making plants grow in particular places*. Geoforum. doi:10.1016/j.geoforum.2013.06.001

Heinonen, U. (2006). Environmental impact on migration in Cambodia: Water-related migration from the Tonle Sap Lake region. *Water Resources Development*, *22*(3), 449–462. doi:10.1080/07900620500482865

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*(15), 1965–1978. doi:10.1002/joc.1276

Hirsch, P., & Warren, C. (1998). *Introduction: Politicisation of the Environment in Southeast Asia. The Politics of Environment in Southeast Asia: Resources and Resistance*. London: Routledge.

Hoanh, C. T., Guttman, H., Droogers, P., & Aerts, J. (2004). Will we produce sufficient food under climate change? Mekong Basin (South-east Asia). *Climate Change in Contrasting River Basins: Adaptation Strategies for Water, Food, and Environment*, *157*, 180.

IPCC. (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability: Working Group I Contribution to the Fourth Assessment Report of the IPCC* (Vol. 4). Cambridge University Press. Retrieved from http://books.google.com/books?hl=en&lr=&id=TNo-SeGpn7wC&oi=fnd&pg=PA81&ots=vO8DugUslB&sig=M7nTB-MZF3j2X_Sw1ZWyz7GrnOc

Ison, L. (2014). IRR releases 44 new rice varieties resilience to climate change. Retrieved from http://www.interaksyon.com/business/81329/irri-releases-44-new-rice-varieties-resilient-to-climate-change

Kelly, P. F. (2011). Migration, agrarian transition, and rural change in Southeast Asia: Introduction. *Critical Asian Studies*, *43*(4), 479–506. doi:10.1080/14672715.2011.623516

Khadria, B., & Meyer, J.-B. (2008). The Role of Migration in Re-structuring Innovation Systems. *Change*, 09.

KOC. (2012). The Cambodian government's achievements and future direction in sustainable development. National Report for Rio+20 United Nations Conference on Sustainable Development. Kingdom of Cambodia.

Kummu, M., & Sarkkula, J. (2008). Impact of the Mekong River flow alteration on the Tonle Sap flood pulse. *AMBIO: A Journal of the Human Environment*, 37(3), 185-192.

UT-Battelle, LLC. (2013). LandScan High Resolution Global Population Data Set.

Leinenkugel, P., Wolters, M. L., Oppelt, N., & Kuenzer, C. (2015). Tree cover and forest cover dynamics in the Mekong Basin from 2001 to 2011. *Remote Sensing of Environment*, *158*, 376–392. doi:10.1016/j.rse.2014.10.021

Lina, H. (2012). Measuring women status and gender statistics in Cambodia through the surveys and census. *Global Forum on Gender Statistics*. National Institute of Statistics, Ministry of Planning.

Ly, P., Jensen, L. S., Bruun, T. B., Rutz, D., & de Neergaard, A. (2012). The system of rice intensification: Adapted practices, reported outcomes and their relevance in Cambodia. *Agricultural Systems*, *113*, 16–27. doi:10.1016/j.agsy.2012.07.005

McSweeney, C., New, M., & Lizcano, G. (2008). UNDP climate change country profiles. University of Oxford. Retrieved from http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/

Mendoza, M. E. T., Naret, H., Ballaran, V. G., & Arias, J. K. B. (2014). Assessing Vulnerability to Climate Change Impacts in Cambodia, the Philippines and Vietnam: An Analysis at the Commune and Household Level. *Journal of Environmental Science and Management*, *17*(2).

Ministry of Agriculture, Fishery and Forestry, Royal Government of Cambodia. (2011). Annual Report and Work Plan 2011-2012.

Ministry of Environment Royal Government of Cambodia. (2011). Building resilience: The future of rural livelihoods in the face of climate change.

Ministry of Environment (MOE) Royal Government of Cambodia. (2002). Cambodia's initial national communication under the United Nations Framework Convention on Climate Change. Ministry of Environment, Kingdom of Cambodia, Phnom Penh: Cambodia.

Ministry of Environment (MOE) Royal Government of Cambodia. (2005). *Vulnerability and Adaptation to Climate Hazards and to Climate Change: A survey of Rural Cambodian Households*. Phnom Penh, Cambodia.

Ministry of Environment (MOE) Royal Government of Cambodia. (2006). *National adaptation programme of action to climate change (NAPA)*. Phnom Penh, Cambodia: Ministry of Environment, Royal Government of Cambodia.

National Institute of Statistics. (2009). *General Population Census of Cambodia 2008 National Report on Final Census Results*. Phnom Penh, Cambodia: Ministry of Planning.

Neou B. (2001). *Tonle Sap Ecosystem and Value.* (Phnom Penh: MoE)

Neupert, R. F., & Prum, V. (2005). Cambodia: Reconstructing the demographic stab of the past and forecasting the demographic scar of the future. *European Journal of Population/Revue européenne de Démographie*, 21(2-3), 217–246.

Open Development Cambodia. Atlas of Cambodia 2015. (2015). *Cambodia Forest Cover 1973-2014* [Raster Data Sets]. Retrieved from http://www.opendevelopmentcambodia.net/maps/downloads/download-forest-cover-data-and-analysis/

Phirun, N., Daravy, K., Hirsch, P., & Whitehead, I. (2011). Improving the governance of water resources in Cambodia: A stakeholder analysis- understanding stakeholders? Roles, perceptions and constraints for effective irrigation and catchment. Cambodia Development Resource Institute Working Paper Series No. 54.

Piper, N. (2008). Feminisation of migration and the social dimensions of development: The Asian case. *Third World Quarterly*, *29*(7), 1287–1303. doi:10.1080/01436590802386427

Potter, R. B. (1992). *Urbanisation in the Third World*. Cambridge, UK: Cambridge University Press.

Rahut, D. B., & Micevska Scharf, M. (2012). Non-farm employment and incomes in rural Cambodia. *Asian-Pacific Economic Literature*, *26*(2), 54–71. doi:10.1111/j.1467-8411.2012.01345.x

RGC, NIS (National Institute of Statistics). (2008). Statistical Yearbook of Cambodia 2008. Phnom Penh: Cambodia: MoE.

Roudy, G. (2002). *Natural Resource Use and Livelihood Trends in the Tonle Sap Floodplain, Cambodia*. London: Department of Environment Science and Technology.

Royal Government of Cambodia, Ministry of Agriculture, Fishery and Forestry (MAFF). (2011). Annual development report for 2010-2011 and target for 2011-2012. Phnom Penh.

Saing, C. H., Hem, S., Ouch, C., & Phann, D. and Pon Dorina, 2012. Foreign Investment in Agriculture in Cambodia. CDRI Working Paper Series No. 60. FAO.

Saray, M. (2010). Groundwater situation in Cambodia. *Paper presented at the second International Forum for Sustainable Asia and the Pacific (ISAP2010)*, Yokohama, Japan.

Scheidel, A., Giampietro, M., & Ramos-Martin, J. (2013). Self-sufficiency or surplus: Conflicting local and national rural development goals in Cambodia. *Land Use Policy*, *34*, 342–352. doi:10.1016/j.landusepol.2013.04.009

Senevirathne, N., Mony, K., Samarakoon, L., & Hazarika, M. K. (2010). Land Use/Land Cover Change Detection of Tonle Sap Watershed, Cambodia. *Proceeding of 31st Asian conference on Remote Sensing ACRS '10*, Hanoi, Vietnam. Retrieved from http://www.a-a-r-s.org/acrs/administrator/components/com_jresearch/files/publications/TS25-3.pdf

Seng, V., Eastick, R., Fukai, S., Ouk, M., Men, S., Yim Chan, S., & Nget, S. (2008). Crop diversification in lowland rice cropping systems in Cambodia: effect of soil type on legume production. Australia Agronomy Conference proceedings. Retrieved from http://regional.org.au/au/asa/2008/concurrent/agronomy-abroad/5671_eastickrj.htm

Snidvongs, A., Choowaew, S., & Chinvanno, S. (2003). Impact of climate change on water and wetland resources in Mekong River basin: Directions for preparedness and action. *Southeast Asia START Regional Center Report*, *12*, 54.

Solar, W. R. (2010). *Rural women, gender and climate change: A literature review and invited perspectives on climate change impacts and processes of adaptation in Cambodia*. America, Cambodia: Oxfam.

Sophal, C. (2009). $12 million rescue package deployed to fight drought. Phnom Penh Post- August 20, 2009. Retrieved from http://www.phnompenhpost.com/business/12-million-rescue-package-deployed-fight-drought

Thomas, T. S., Ponlok, T., Bansok, R., DeLopez, T., Chiang, C., Phirun, N., & Chhun, C. (2013). Cambodian agriculture: Adaptation to climate change impact. International Food Policy Research Institute Discussion Paper 01285.

Tiet Khan, P. (2013). Sustainable aquaculture in the Mekong River Delta. *Journal of Ocean Technology*, *8*, 57–65.

TKK and SEA START RC. (2009). *Water and Climate Change in the Lower Mekong Basin*.

Turunen, J., Snäkin, J. P., Panula-Ontto, J., Lindfors, H., Kaisti, H., Luukkanen, J., ... & Mang, C. (2009). Livelihood resilience and food security in Cambodia.

UNFPA. (2012). *Migration in Cambodia: Report of the Cambodian Rural Urban Migration Project*. Phnom Penh, Cambodia: Ministry of Planning.

UNICEF. (2010). Cambodia Statistics. Retrieved from http://www.unicef.org/infobycountry/cambodia_statistics.html

UNIFEM. WB, ADB, UNDP and DFID/UK. (2004). A Fair Share For Women: Cambodia Gender Assessment. UNIFEM, WB, ADB, UNDP, DFID/UK.

United Nations Department of Economic and Social Affairs, Population Division. (2013). World Population Prospects: The 2012 Revision (DVD). Retrieved from http://esa.un.org/unpd/wpp/Excel-Data/population.htm

Uy, D., Hak, S. C., Huy, C., Srey, M., Chunhieng, T., Phoeurng, S., & Fredericks, D. et al. (2010). Comparison of tube-well and dug-well groundwater in the arsenic polluted areas in Cambodia. In *Southeast Asian Water Environment 4* (pp. 41–46). London, UK: IWA publishing.

World Bank. (2006). Environmental Impact Assessment Regulations and Strategic Environmental Assessment Requirements: Practices and Lessons Learned in East and Southeast Asia. Retrieved from http://www.worldbank.org/eapenvironment/sea-asia

World Bank. (2011). Poverty headcount ratio at national poverty line (% of population): Cambodia. Retrieved from http://data.worldbank.org/country/cambodia

World Bank. (2011). *Vulnerability, risk reduction, and adaptation to climate change: Cambodia*.

World Bank. (2013). *World Development Indicator*.

Yu, B., & Diao, X. (2011). *Cambodia's agricultural strategy: Future development options for the rice sector. A policy discussion paper*. Cambodia Development Resource Institute.

Zhao, D., Ford, R., Makara, O., Chhay, N., Fitzgerald, M., & Snell, P. (2014). *Developing rice cultivars for Cambodia and Australia.* Australian Centre for International Agricultural Research.

Joseph P. Messina is a professor of Geography. He earned a Ph.D. in 2001 from UNC-Chapel Hill and is the Associate Dean for Research for the College of Social Sciences at Michigan State University. His general research interests are in population environment interactions, medical geography, and geospatial methods.

Tanita Suepa completed the Ph.D. Program in Department of Geography at Michigan State University, USA, from 2008-2013. Her dissertation Topic: Satellite Time-series Data for Vegetation Phenology Detection and Environmental Assessment in Southeast Asia. From 1995-1998 she earned the Master of Urban and Regional Planning from the Faculty of Architecture at Chulalongkorn University, Thailand. Her Thesis Topic was The Development Planning for Residential Land Use in the Suburban Area: A Case Study of Min Buri District, Bangkok. From 1991-1994 she earned a Bachelor of Arts (Geography) from the Faculty of Arts, Chulalongkorn University, Thailand. Her position is Chief of Instructional Media and Curriculum Development Division, Technology Transfer and Knowledge Development Office, Geo-informatics and Space Technology Development Agency (GISTDA). Her research interests include Geo-informatics technology for global, climate, and environmental changes, environmental model, remote Sensing for vegetation phenology detection, and cartographic design.

Sieg Snapp is a soils and cropping systems ecologist at Michigan State University and Associate Director of the Center for Global Change and Earth Observations. She has edited two books and published more than a 100 journal articles and extension bulletins on sustainable intensification, agricultural systems, and participatory action research. Her research interests include international agricultural system design for a changing climate and understanding factors driving land management in tropical Africa and processes that can be harnessed for sustainable production. She has pioneered the development of multipurpose crops for food and environmental security, including the first agronomic reports on perennial wheat and perennial pigeonpea. Dr. Snapp has extensive experience in the use of participatory action research and extension, and a commitment to co-learning. She is possibly best known for being the 'mother' of the mother and baby trial design, as a means to support participatory research, communication and innovation.

Jennifer M. Olson is a geographer conducting research on the impacts of climate change on agricultural communities, mostly in Africa.

A. Pouyan Nejadhashemi received his Ph.D. in the area of Bioenvironmental and Water Resources Engineering from the Biological Resources Engineering Department at the University of Maryland, College Park (UMCP) in 2006. His college studies and postdoc experience have given him solid knowledge in different branches of water resources and agricultural engineering. In addition, He possess strong skills in computer programming and executing various hydrologic/agricultural models. He joined Michigan State University (MSU) in August 2008 as a tenure track assistant professor in the area of water resources engineering and ecohydrology. Dr. Nejadhashemi's specific interests are in sensitivity and uncertainty analysis of water quality mitigation approaches to address climate change, environmental impact assessment, soft computing applications in water resources, and development of Decision Support System for human impact evaluation on ecosystem sustainability, and evaluation and development of watershed/water quality models.

Sarah Murray has a Master's degree in Urban and Regional Planning from Michigan State University (MSU), where as a Foreign Language Area Studies Fellow and graduate research assistant with the Global Center for Food Systems Innovations she focused on the impacts of population mobility on food security in developing countries. While at MSU, was an Environmental Science and Policy Program Fellow and Research Symposium Organizing Committee member and received the American Institute of Certified Planners 2015 Outstanding Planning Student Award. Murray has bachelor's degrees in both Global and International Studies and French from Western Michigan University. In August 2015, she joined the C.S. Mott Foundation as a Program Assistant under the Environment Division.

Nathan Moore completed his PhD in 2004 from Duke University on the influence of irrigation or precipitation in the Texas High Plains. At MSU he studies land-atmosphere interactions associated with land use change in East Africa, the Amazon Basin, China, and other dynamic areas.

April Frake earned her Bachelor's and Master's degrees from the Department of Geography at the University of North Carolina at Greensboro in 2012 and 2014, respectively. She is currently a Ph.D. student under the supervision of Dr. Joseph Messina at Michigan State University. Her research is centered on land use and land cover change as it relates to infectious disease transmission.

Peilei Fan is an associate professor of urban and regional planning at School of Planning, Design, and Construction and Center for Global Change and Earth Observations at Michigan State University.

Umesh Adhikari's research focuses on impacts of climate change on water resources and agriculture.