地理研究 第63期 民國104年11月
Journal of Geographical Research No.63, November 2015
DOI: 10.6234/JGR.2015.63.04

亞太地區氣候變遷與森林適應

Climate Change and Forest Adaptation in the Asia-Pacific

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摘 要

氣候變遷已對亞太地區造成生態、社會及經濟的嚴重威脅。由於體認到亞太地區森林生態系與森林產業之重要，以及林業與氣候變遷減緩之密切連結，本文將回顧亞太地區有關森林對氣候變遷的適應與減緩之現行政策、科學及技術，總結有關此議題目前的文獻情況，並提出知識與政策之落差。本文在評估亞太地區林業與森林經營的現行狀況、氣候與生態系模擬的發展、以及政策在適應及減緩能力的任務後，據此提出三個主要建議：(1)跨領域及跨國界的協同；(2)發展國家政策架構；(3)增加區域及地方的特殊研究，例如特殊物種模式發展，以增加權益關係人及科學家獲得足夠訊息。最後，透過永續森林經營倡議，以達成減排目的，並獲致附加的環境及社經目標，是至為關鍵。

關鍵詞：亞太地區、氣候變遷減緩、永續森林經營

Abstract

Climate change poses serious ecological, social and economic threats to the Asia-Pacific (AP) region. Recognizing the importance of forest ecosystems and the forest industry in the AP, as well as the strong connection between forestry and climate change mitigation, this paper reviews existing policy, science, and technology related to the adaptation and mitigation of AP forests to climate change. We summarize the current state of literature related to these topics and identify knowledge and policy gaps to be addressed. After evaluating the current state of forests and forest management in the region,

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developments in climate and ecosystem modeling, and the role of policy in the adaptive and mitigative capacity of AP nations, we provide three main recommendations for improvement of forest management and decision-making in the region: 1) cross-disciplinary and cross-national collaboration; 2) the development of national policy frameworks; and 3) an increase in regionally and locally specific research, including the development of species-specific models, to increase the availability of relevant information to stakeholders and scientists. Finally, we emphasize the importance of using sustainable forest management initiatives in meeting emissions reduction targets and in achieving additional environmental and socio-economic objectives.

Keywords: Asia-Pacific (AP) region, climate change mitigation, sustainable forest management

Introduction

Climate change is one of the most challenging issues of the 21st century. Although climate change will influence humanity and ecosystems all across the globe, it is expected to be most detrimental to the least developed, most impoverished and vulnerable nations. This risk applies to much of the Asia-Pacific (AP) region, which is expected to be severely impacted by climate change (Christensen *et al.* 2007; Vickers *et al.* 2010). Climate change poses serious ecological, social and economic implications, as the AP contains more than half of the world's population (UNEP 2010), a large portion of global forest cover (FAO 2010a), much of the world's biodiversity (CEPF 2014), and the highest number of threatened species (UNEP 2010). However, the AP region also has a strong potential to contribute to climate change mitigation and adaptation efforts through its carbon sequestration capacity and human resources (Vickers *et al.* 2010).

Countries in the AP are diverse in regards to their social and economic dependence on forests, the extent of forest cover, level of success in sustainable forest management, and in their vulnerability to climate change (FAO 2010a). Those who have contributed the least to climate change are expected to bear a disproportionately large proportion of the impacts, and tend to have fewer resources to cope with the anticipated outcomes of climate change (Heltberg *et al.* 2009). The risk to these groups is a concern for several developing nations, and even communities within more developed nations, throughout the AP region. The adaptive capacity of these countries can be improved by addressing not only the direct impacts of climate change, but also indirect factors such as poverty, food and resource availability, and economic development, which may be putting these nations more at risk and limiting their ability to effectively respond to climate change (FAO 2010a; UNFCCC 2014a).

Forest ecosystems are particularly vulnerable to climate change, as tree species are adapted to specific ranges of temperature, moisture, and nutrient conditions, and may be unable to adapt at the pace with which these conditions are anticipated to change (FAO 2011a; Krzyzanowski 2014b). Shifts in these conditions can therefore alter a stand or population's ability to survive and reproduce (FAO 2010a; Krzyzanowski 2014b). Forests' sensitivity to climate leads to uncertainty with regards to how forest ecosystems and communities dependent upon them will fare in the future. Loss or degradation of these ecosystems will be catastrophic for the millions of people who depend on forests as a source of food, fuel, or income (Krzyzanowski 2014a). Furthermore, climate change in the AP region may trigger a positive feedback loop between climate and the carbon cycle, transitioning forests from carbon sinks to carbon sources (Bonan 2008; Christensen *et al.* 2013), thereby perpetuating warming trends and the associated environmental, social, and economic changes.

Recognition of this connection between forestry and climate change and the ability of the forestry sector to either mitigate or accelerate climate change is improving (Vickers *et al.* 2010). The forest industry contributes approximately 20% of global anthropogenic greenhouse gas (GHG) emissions (IISD 2013; UN-REDD 2009a), mainly from deforestation, forest degradation, and poor soil management (Bustamante *et al.* 2014). As such, mitigation initiatives in this sector are critically important for meeting emission reduction targets (Bustamante *et al.* 2014). The success of these mitigation strategies however, requires access to quality information that can guide the development of policy and management plans, as well as sufficient capacity and will of governments to develop, enforce, and monitor these initiatives. This type of capacity is unevenly distributed throughout the AP and is often hindered by a lack of scientific or technological ability, as well as poor socio-economic conditions (ADB 2009; FAO 2010a). If these barriers can be overcome, forests have the potential to mitigate climate change through carbon sequestration, as well as offer environmental and socio-economic benefits through multifaceted, sustainable, and integrative approaches to management (Canadell & Raupach 2008; Innes *et al.* 2009).

Further development in research and technology is essential for reducing forest vulnerability to climate change and improving adaptive capacity. Numerous models related to climate change and ecological systems have already been developed and have helped to improve our understanding of the potential changes and challenges to be expected throughout the AP (i.e. Cao *et al.* 2014; Girvetz *et al.* 2009; Hansen *et al.* 2013; Kou *et al.* 2014; Lu *et al.* 2015; Wang *et al.* 2015; Zhang *et al.* 2015). Effort has been made by several organizations including the Intergovernmental Panel on Climate Change (IPCC), the Food and Agriculture Organization (FAO), the United Nations Framework Convention on Climate Change (UNFCCC), as well as several nations and research institutions, to understand the science behind climate change and to develop effective adaptation and mitigation strategies. The work of these organizations is vital for improving current technology and research, and in addressing policy gaps. The networks established by these organizations also provide a means for knowledge dissemination, training, and collaboration between experts from different locations and backgrounds (FAO 2011a; FGLG 2014). Further development in this field will continue to improve our capacity to adapt to and mitigate climate change through improved policy and management strategies. These strategies should aim to provide a means of adapting forestry practices to accommodate uncertainty in climate and forest ecosystems changes, while exploiting the mitigation potential of forests through carbon sequestration. This goal should be addressed through multiple research facets, including changes in the hydrological cycle, carbon cycle and storage (Bonan 2008), ecosystem dynamics, and changes in niche distribution (Innes *et al.* 2009; Nitschke & Innes 2008). Although advancements have been made in this field over recent years leading to improved understanding and policy development, numerous knowledge and policy gaps remain, particularly in regions with low adaptive capacity and limited availability of resources for investment in research and development.

The goal of this paper is to help address these gaps by reviewing existing policy, science, and technology as they relate to the adaptation and mitigation potential of AP forests to climate change. We evaluate the strengths and weaknesses of current literature covering these topics in order to identify the knowledge and policy gaps that need to be filled. Additionally, we present future directions and recommendations for research and policy in order to maintain ecologically and economically viable forests in the face of climate change. For the purposes of this study, the AP region is defined to include all countries within East Asia, South Asia, Southeast Asia, and Oceania, as defined by the FAO (2010a).

Asia-Pacific Region

The AP region contains approximately 18.3% of the world's forests (FAO 2010a) and more than 60% of the global population (UNEP 2010), with both forests and people being unevenly distributed throughout the region. South Asia contains 2% of global forests and 23.4% of the global population, while Southeast Asia contains 5.3% of global forests, but only 8.5% of the world's people (FAO 2010a). This uneven distribution is also reflected in the socio-economic stability, quality of life, and legislative capacity of the AP, all of which have a strong influence on a region's adaptive capacity.

It is anticipated that the AP region will warm faster than the global average and experience some of the world's most severe climate change impacts (ADB 2009; Christensen *et al.* 2007). The IPCC 5th Assessment Report (AR5) indicates that changes in climate are highly variable between regions within the AP (IPCC 2013). This is partly due to the diversity of biomes, topography and local weather within the region, as well as the influence of large-scale phenomena such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (Christensen *et al.* 2013). Major climate systems and seasonal events in the region are expected to shift, including changes in the arrival time and intensity of the Asian monsoon, and an increase in frequency and intensity of extreme weather events, such as tropical cyclones (Ahmed & Suphachalasai 2014; Christensen *et al.* 2013; Knutson *et al.* 2010). Changes in climate have already occurred in some areas, including decreases in overall rainfall, increased intensity of rainfall events, more frequent heat waves, a higher number of tropical cyclones, and shifts in the onset of rainy seasons, among others (ADB 2009; FAO 2010b). These changes have and will continue to cause increases in flooding, landslides, drought, soil erosion, and risk and severity of forest fires, having detrimental effects on forest ecosystems (ADB 2009; FAO 2010a). These changes also jeopardize the immense, and already vulnerable, biodiversity of the region (CEPF 2014; FAO 2007), as well as the socio-economic stability that is tightly linked to vulnerable industries such as forestry

(FAO 2010a).

2.1 Social and economic dependence on forestry in the Asia-Pacific

Understanding the impacts of climate change on forests is critical for people of the AP, as they rely heavily on forests for socio-economic needs, ecosystem services, and cultural and traditional practices (ADB 2009). Forests are an essential component of regulating ecosystem function and play an active role in influencing annual rainfall, controlling river runoff, protecting watersheds, buffering landslides, and reducing the intensity of cyclones and other natural disasters in coastal areas (Ahmed & Suphachalasai 2014; Vickers *et al.* 2010). The decreased vitality and productivity of forests resulting from climate change may hinder these functions and alter ecosystem dynamics (Innes *et al.* 2009). This could be detrimental to the estimated 450 million people in the AP who are directly dependent on forests for their livelihood (RECOFTC 2013a) — 60 million of whom are indigenous people (Vickers *et al.* 2010). Poor and marginalized societies are expected to be the most vulnerable to climate change (Heltberg *et al.* 2009; Kumar 2012). With over half of the world's impoverished people living in this region, many of whom depend on climate sensitive industries such as forestry and agriculture (Ahmed & Suphachalasai 2014) for their livelihood, climate change poses a severe threat to socio-economic stability, and may hinder the region's efforts to alleviate poverty (ADB 2009).

2.2 Forest-related GHG emissions in the Asia-Pacific

Deforestation and forest degradation currently account for 20% of global greenhouse gas emissions (IISD 2013; UN-REDD 2009a), with parts of the AP, most notably Southeast Asia, having some of the highest deforestation rates in the world (FAO 2010a) and producing per capita emissions that are 42% higher than the global average (ADB 2009). In 2000, Southeast Asia alone was responsible for 12% of global GHG emissions, 75% of which were the result of land-use changes and forestry activities (ADB 2009). Indonesia, home of the third largest tropical forest in the world (FGLG 2014), is also the world's top emitter of GHGs from deforestation and land-use changes (Vickers *et al.* 2010). Anthropogenic alteration of forests not only releases GHGs, but also results in a loss of important carbon sinks (Gibbs *et al.* 2007). As such, forest ecosystems in the AP have an immense capacity to contribute to climate change.

Due to the high GHG emissions associated with forest activities, the forestry sector can play an important role in mitigating climate change. Forests contain over half of the global carbon held in terrestrial vegetation and organic soil, with growing forests sequestering large amounts of carbon in their biomass (Fredeen *et al.* 2005). The capacity of forests to store carbon varies between climate zones and tree species, with high carbon storage being associated with relatively cool climates, moderately high precipitation and old growth forests (Fredeen *et al.* 2005; Keith *et al.* 2009). As such, the AP is an important region for carbon sequestration. For instance, the temperate, moist eucalyptus forests of southeastern Australia are estimated to contain the world's highest total aboveground biomass carbon density (Keith *et al.* 2009). Key forestry activities that should be targeted to mitigate carbon emissions in this region include: increasing forested land area via reforestation and afforestation, increasing the carbon density of existing forests, and reducing emissions from degradation and deforestation (Canadell and Raupach 2008).

2.3 Forest disturbances in the Asia-Pacific

The anticipated increase in extreme forest disturbances due to climate change, such as forest fires and insect outbreaks (Innes *et al.* 2009), adds to the already prevalent risk of these events triggering large releases of carbon due to increased tree mortality (Canadell & Raupach 2008). Due to this potential change in magnitude and frequency of forest disturbances, many adaptation strategies focus on reducing the potential impact of these events (Innes *et al.* 2009). The risk of these events varies between ecosystems. Monospecific ecosystems, such as some temperate and boreal forests, as well as many plantations, are comprised of very few species, leading to low biodiversity and decreased ecosystem resilience. As such, these biomes are more susceptible to pathogen outbreak and spread associated with climate change (Innes *et al.* 2009). One such event has already occurred in the forests of British Columbia, Canada, where an outbreak of the Mountain Pine Beetle has killed approximately 18.1 million ha of lodgepole pine (Government of British Columbia 2015; Innes *et al.* 2009). This, in combination with an increase in forest fire occurrence, has transformed the region from a carbon sink (prior to 2000) to a carbon source, with positive net carbon emissions from the region expected to continue for the next several decades (Canadell & Raupach 2008). Another concern within the AP is the peat swamp forests of Southeast Asia, which are anticipated to release large amounts of carbon in response to projected drying in the region (Canadell & Raupach 2008). Additionally, a warmer, drier climate may generate a positive climate feedback loop through a decrease in evaporative cooling, increased release of CO_2, and forest diebacks that transition forests from carbon sinks to carbon sources (Bonan 2008; Christensen *et al.* 2013).

2.4 Biodiversity in the Asia-Pacific

Species biodiversity and forest ecosystems are strongly linked; the conservation of biodiversity requires healthy and productive forest ecosystems, while high levels of biodiversity can increase the resilience of forests (FAO 2011a; Innes *et al.* 2009). Climate change is expected to exacerbate the risks faced by many already threatened and endangered species in the AP by damaging forest ecosystems, reducing suitable habitat, altering seasonal cycles (upon which reproduction, migration, and hibernation depend), and increasing the prevalence of invasive species and the risk of disease (ADB 2009; Ahmed & Suphachalasai 2014; Innes *et al.* 2009). The incidence of pest and disease outbreaks in native populations, as well as the spread to previously unoccupied areas, are already prevalent in the region, and this issue is anticipated to worsen as a changing climate continues to weaken the defenses of forest ecosystems (FAO 2010a). This will lead to forest degradation, loss of productivity, and the potential transition of forests from carbon sinks to sources (FAO 2010a). The loss of high quality forest habitat will also jeopardize the survival of many species and lead to a significant loss of regional and global biodiversity (ADB 2009), in addition to losses in ecosystem services (Innes *et al.* 2009).

Developments in Research and Technology

The use of generalized, large-scale studies is not sufficient to understand the subtle variations in climate change impacts between regions and ecosystems. The accuracy of predicted changes in climate is limited by the resolution of the climate model used, particularly in regions where local topography and global climate phenomena greatly influence factors such as precipitation and temperature (Christensen *et al.* 2013). The IPCC's AR5 stressed the need for regional high-resolution models to address the variability caused by complex terrain in regions such as Southeast Asia (Christensen *et al.* 2013; IPCC 2013). Current models cannot generate sufficiently accurate results, as they are unable to account for small variations at the landscape-scale that are essential for determining precipitation patterns. For instance, ENSO and IOD can complicate climate projections, as is the case in Southeast Asia, where projections have indicated vastly different trends across the region and between seasons, but with low accuracy. This limited accuracy is due to the large scale of the model used and the exclusion of ENSO and IOD impacts (Christensen *et al.* 2013). The use of Regional Circulation Model (RCM) downscaling, as opposed to General Circulation Models (GCMs), can provide more detail by utilizing more realistic topographic forcing (Christensen *et al.* 2013), and can improve the accuracy of projections for a given location. Increased research and effort in creating localized models is imperative for developing well-informed climate change adaptation and mitigation strategies for any specific region.

3.1 Recent advancements in modeling

3.1.1 Climate modeling

Climatic information is essential for conducting any climate change-related research. Despite the accumulation of large-scale climate data in recent years (IPCC 2014; Mitchell & Jones 2005), it remains a challenge to obtain accurate climatic information for specific locations, especially for both historical and future periods. High-resolution (up to 1 x 1 km) climate data from WorldClim (Hijmans *et al.* 2005) addresses this need to a certain extent, but an improved data source, developed by the PRISM Group, has since become available. These data use expert knowledge adjustments to consider the effects of the sides of mountain ranges and topographic facets on the spatial patterns of climate variables (Daly *et al.* 2002, 2008).

ClimateAP is an example of a downscaled, high-resolution climate model, developed recently to address local accuracy gaps in technology. It makes use of the best available climate data, including

PRISM data. ClimateAP was developed based on the same algorithms applied in ClimateWNA (Wang *et al.* 2012), which has been widely used throughout western North America. However, ClimateAP was extended to cover the entire AP region. It generates climate data for historical (1901-2012) and future periods (2020s, 2050s and 2080s for most of the GCMs from the IPCC CMIP5 project) for specific point locations (scale-free). Both desktop and web-based versions of the model are freely available. The desktop version allows users to generate climate data for an unlimited number of locations, while the web version is a Google Maps based tool that facilitates spatial visualization of climatic variables and instant access to climate data. ClimateAP has improved the accuracy of regional climate modeling, reduced difficulty in accessing climate data, and has provided a model applicable to any location in the AP that can be used by anyone, regardless of previous modeling knowledge (Wang *et al.* 2014). The increased accuracy of climate projections for specific locations produced by this model will improve climate-based experimental design, while its accessibility will facilitate modeling of climatic effects on ecosystems and species (Wang *et al.* 2014).

Climate Wizard is another high-resolution, web-based modeling tool that allows regionally- and temporally-specific analyses of climate change, but uses limited climate variables and is not updated to consider the most recent GCM predictions (Girvetz *et al.* 2009). Similar to ClimateAP, Climate Wizard can be used to understand climate change impacts and adaptation planning at the local level, through the production of maps, graphs, and tables, and is accessible to users with a wide range of technical proficiency (Girvetz *et al.* 2009).

WorldClim is a source of free, high-resolution global climate data that can be used for spatial modeling. The data contain climate layers for past and current conditions generated through the interpolation of average monthly climate data from global weather stations, as well as future projections (Hijmans *et al.* 2005). The accuracy and accessibility of the data, and the scientific knowledge gained through the use of these tools makes them important contributors to the development of improved policy and adaptation strategies throughout the AP. However, access to climate data for particular species locations requires users to have some GIS background.

3.1.2 Niche-based ecological modeling

Most forest tree species are adapted to a specific range of climatic conditions (Davis & Shaw 2001). Due to the long lifecycle and slow rate of migration of forest trees, rapid climate change will likely result in a mismatch between the climate that trees are historically adapted to and the climate that trees will experience in the future (Aitken *et al.* 2008). Such a mismatch may substantially compromise productivity and increase the vulnerability of species to disturbances such as insects and pathogens (Fettig *et al.* 2013; Hamann & Wang 2006; Kurz *et al.* 2008). In order to maintain an adaptable and economically viable forestry industry, modeling and projection of future climate niches for forest tree species is essential. Research and application of species distribution models (SDMs) and ecological niche models (ENMs) are widely used in North America and Europe (Araujo & Peterson 2012; Keenan

2015), but are limited throughout the AP (Kou *et al.* 2014). Recently, ENMs were developed to project changes in climatic niches for economically important species in China (Wang *et al.* 2015). This modeling approach utilized climate variables from the previously mentioned ClimateAP to provide the most accurate projections possible (Wang *et al.* 2014). In particular, the maps generated through these models have been overlaid onto Google Maps and integrated into the online version of ClimateAP. Users can then directly visualize the maps at large- (species wide), or local- (specific location), scales and download the data as GIS layers to their computer. This promotes simple and effective knowledge transfer from scientists to users. The application of SDMs and ENMs to a broad range of locations and species can provide the necessary information for managers and decision-makers to develop sustainable forest management plans to help ecosystems adapt to and mitigate climate change impacts. Recent research suggests that the current ranges of some economically and environmentally important species (including Chinese fir, Masson pine and Blue Gum) are predicted to contract (Kou *et al.* 2014; Wang *et al.* 2014), so an understanding of these changes will be crucial to maintaining productive plantations and forest ecosystems in the future.

Visual depiction of predicted or observed changes in forest ecosystems provides an effective approach to clearly convey information to forest managers and decision-makers. ClimateAP and the ecological models mentioned above generate maps to demonstrate how climatic variables and tree species' distributions are projected to change over space and time (Kou *et al.* 2014; Wang *et al.* 2014). Similarly, high-resolution maps of global forest cover change provide an effective way to understand large-scale changes to forest ecosystems and convey to decision-makers the key areas of deforestation and degradation where additional attention is needed (Hansen *et al.* 2013). Recent generation of these maps, completed using Earth observation satellite data (Hansen *et al.* 2013), has shown that from 2000 to 2012, Indonesia experienced the largest increase in forest loss of any country. This information was the first of its kind and allowed for very detailed observations to be made about changes in forest cover. These maps have helped to identify areas of most concern, while also providing information about where illegal logging may be occurring and increasing the accountability of countries in their efforts to reduce deforestation and increase reforestation (Hansen *et al.* 2013).

3.1.3 Process-based ecological modeling

Another method to predict shifts in species ranges, growth and productivity under various climate change scenarios is the use of process-based models, such as Physiological Principles in Predicting Growth (3-PG) (Lu *et al.* 2015). These models project anticipated changes in the production of harvestable biomass, and provide information that plays an important role in developing forest management strategies to maintain a viable industry and avoid socio-economic loss. Managers and planners can use this information to develop adaptation strategies and improve sustainable forest management practices, leading to improved decision-making, particularly regarding site and species selection for plantations (Lu *et al.* 2015).

FORECAST Climate, developed by Seely *et al.* (2014), is an ecosystem-based model used to assess the long-term impacts of climate change and forest ecosystem management strategies on forest growth rates and mortality (Kang *et al.* 2014a). A recent application of this model to Chinese fir plantations in Fujian, China has provided insight into the potential impacts of alternative climate change scenarios on the long-term growth and development of this species (Kang *et al.* 2014b). Results from this study can be used to develop well-informed, long-term management strategies (Kang *et al.* 2014a). The output of FORECAST Climate can be used in conjunction with a landscape-scale model, such as Landscape Summary Tool (LST), to analyze tradeoffs between economic- and ecosystem-related variables in the context of climate change under a series of alternative management scenarios. This straightforward ranking of management options acts as a decision-support tool for the development of forest management adaptation strategies (Kang *et al.* 2014a). A structured decision-making approach, such as this, is key to determining the suitability of adaptation strategies and reducing site-specific vulnerabilities to climate change, while maintaining forest management objectives (Kimmins *et al.* 1999; Ogden & Innes 2009).

The tree and climate assessment (TACA) model was developed to model a species' resilience and vulnerability to climate change within its fundamental niche by examining how climate change impacts a species ability to regenerate (Nitschke & Innes 2008). This model focuses on a species during its most sensitive stage of development, the regeneration phase, assuming that if a species is unable to regenerate, it cannot compete, and is therefore vulnerable to a dramatic decrease in abundance, distribution, and persistence (Mok *et al.* 2012; Nitschke & Innes 2008). TACA accounts for microclimatic and edaphic conditions, as well as other processes that impact the growth, mortality, abundance, and distribution of a species under climate change. It is therefore able to provide a finer scale representation of species responses compared to other tools, such as bioclimatic envelope models (Nitschke & Innes 2008). An expanded version of TACA, including TACA-GEM, TACA-GAP and LANDIS-II, has recently been developed and applied to southeastern Australia (Nitschke 2014). TACA-GEM models the suitability of a site for species regeneration and survival, TACA-GAP estimates annual net primary productivity under given climatic parameters, and LANDISS-II is a spatial forest simulation model that generates historic and future climate scenarios. Together, these three models project the spatial response of species and ecosystems to climate change. Alternative management scenarios can be included in the models to test the interaction between management, climate change, and ecosystem services, and to determine the most appropriate strategies for achieving desired management objectives (Nitschke 2014).

Effective forest management also requires an understanding of how the physical components of an ecosystem, such as the hydrological cycle, will be impacted by climate change. The eco-hydrological model, DLM-Ecohydro, is a unique modeling approach that integrates both hydrology and ecology (Chen 2014) to generate a more accurate representation of water movement through physical and biological systems under various climate scenarios. The influence of climate change on hydrology will have a significant impact on forest ecosystem health (Yan *et al.* 2013). Thus, hydrological models such as DLM-Ecohydro are important tools to provide a more holistic understanding of the impacts of climate change on forest ecosystems, thereby allowing resource managers and planners to develop appropriate adaptation strategies.

The success of strategies that aim to reduce carbon emissions from forestry activities and improve the sequestration of carbon in forest biomass, such as REDD+ (See Section 5), require accurate data and the monitoring of land use changes and forest carbon storage and fluxes (Asner *et al.* 2010). Accurately calculating the carbon density of forests will ensure countries are meeting their emissions reduction targets associated with carbon storage and sequestration, and lead to more accurate emissions reporting. Techniques to accurately measure the carbon density of forests and rates of deforestation are therefore crucial in order to reduce the uncertainty of emissions estimates from forestry activities (Baccini *et al.* 2012). The use of multi-sensor satellite data (Baccini *et al.* 2012) and light detection and ranging (LiDAR) (Asner *et al.* 2010; Cao *et al.* 2014) has been shown to vastly improve the accuracy and spatial resolution of data estimating aboveground vegetation carbon density compared to previous methods of data collection. More recently, work has been done to estimate not only the aboveground, but also the belowground biomass components of subtropical forests using small-footprint LiDAR (Cao *et al.* 2014). This more holistic understanding of biomass, and therefore carbon, in an ecosystem is necessary for accurate assessment of forest ecosystem carbon storage and emissions. However, these remote-sensing options cannot measure forest carbon stock directly, and thus require concurrent ground data collection (Gibbs *et al.* 2007). Regression models can also be used to convert forest inventory data to estimates of aboveground biomass (Gibbs *et al.* 2007). The model developed by Chave *et al.* (2005) has been proven reliable in its prediction of aboveground biomass for a broad range of tropical forests including secondary, old growth, moist, and montane forests. Improved modeling and mapping of carbon storage in forest biomass can improve carbon storage estimates and help generate consensus on the contribution of anthropogenic forest alterations to climate change, as well as lead to improved planning and assessment of mitigation strategies (Asner *et al.* 2010; Chave *et al.* 2005).

Once the amount of carbon stored in an ecosystem is known, the ecosystem carbon dynamics can be modeled to project changes in variables such as carbon storage and carbon flux under various climate change scenarios and management practices (Li 2015). Analyzing how forest management impacts carbon storage capacity and GHG emissions will enable the development of management practices focused on climate change mitigation. This in turn will help reduce the contribution of forests to climate change and increase the resilience of these ecosystems (Li 2015).

3.2 Integration of models

The amalgamation of several models of various types, including climate, ecosystem, and process-based models, can generate a holistic view of projected ecosystem changes due to climate change, and help managers and decision-makers to make sound decisions on how to best manage forests while mitigating and adapting to climate change. An integrated model framework developed by Li

(2015) applies various models and methods to seven different indicators that evaluate sustainable forest management under climate change. The resulting information is then incorporated into a trade-off analysis framework for decision-making and planning in order to assess the impacts of different forest management regimes on ecosystem values, evaluate the influence of alternative management strategies on those values and their tradeoffs, and address some of the complex effects of climate change on ecosystems and decision-making processes. The information is then ranked using risk classes so that it can be shared simply and coherently with decision-makers and stakeholders.

Development of technology and improved scientific knowledge are important, but in order to be effective, increased collaboration and dissemination of knowledge between countries, particularly between developed and developing nations, is essential. Several AP countries would benefit greatly from increased international collaboration and knowledge sharing from regions with more developed technology and highly trained personnel, in addition to guidance on decision-making and assistance with implementing sustainable forest management strategies (FGLG 2014).

Development of Government Policy and Action

Forest management and climate change policies vary considerably throughout the AP region. There has been a shift in the region over the last two decades away from timber-focused management and towards the preservation of ecosystem services (FAO 2010a), such as storage of carbon in biomass. Although the overall rate of deforestation in the AP region has decreased, this is attributed to substantial effort from only a few countries, namely China, India, Nepal, and Vietnam, while other regions, particularly Southeast Asia, continue to have high rates of deforestation (FAO 2011b; Vickers *et al.* 2010). Furthermore, there is considerable imbalance between AP nations with regards to their economic stability, levels of poverty, availability of food and water resources, social and ecological vulnerability, and thus their resilience and adaptive capacity to climate change (FAO 2010a; Vickers *et al.* 2010). Regions with high levels of poverty, income inequality, and weak political and institutional frameworks causing government deficiencies will be most vulnerable to the uncertainties of climate change (FAO 2010a).

4.1 Government and economic Impacts

Most AP countries have national policy and initiatives regarding forest resource management, law, and enforcement. The type and effectiveness of forest governance and climate change policy, however, is highly variable between, and even within, AP countries (Vickers *et al.* 2010). For example, Malaysia's National Forestry Policy (NFP) is used to determine the classification, use, and management of forests in the country, and recognizes the importance of biological conservation and community involvement in forest development. However, NFP is only adopted by the states in Peninsular Malaysia, while Sabah and Sarawak on the island of Borneo follow their own forestry policy, which is not updated or revised as frequently as NFP (ITTO 2004). This regional disjunction is consistent with all environmental and forestry-related policies in Malaysia, as individual states have authority over policy implementation and are able to make revisions and alter policy to suit their needs (ITTO 2004). Each state is unique regarding their forest-related activities and socio-economic dependence on forests, so the ability to tailor policy to their needs may make the efforts of each state more effective. However, a lack of unity among states may also hinder national or international efforts to implement policy to mitigate the effects of climate change on forests.

The desire for economic growth, infrastructure development, and natural resource extraction is another barrier affecting the preservation of forests, particularly in developing countries (FAO 2010a). Forest policy often does not adequately address these conflicting interests, or provide frameworks that consider the trade-offs between them. In the past this has led to poor policy implementation and illegal activity (i.e. illegal logging, illegal harvesting and trade of forest products) in order for resource demand and income needs to be met (FAO 2010a). Initiatives are more likely to succeed if they are established based on the interests of local forest dependent communities (FGLG 2014). Some of the current issues leading to high rates of deforestation in the AP region include inconsistent legal frameworks, weak local governance, extensive corruption in the forestry sector, ineffective forest management, and unclear land tenure leading to conflicts over ownerships, and limiting the government's ability to control the conversion of forests into production landscapes (FAO 2010a; FAO 2011b; FGLG 2014). An example of weak forestry policy is in Indonesia, where current policy provides more incentive to convert forests than to preserve them (FGLG 2014). Discussion around forest preservation strategies should account for how agriculture and food security relate to forest conservation and mitigation activities, as high levels of poverty and a lack of food security can lead to agriculture being an influential driver of deforestation (Aliadi & Tropika 2012). The balance between agricultural development and forest conservation needs to be addressed so as not to decrease food security in rural communities (Canadell & Raupach 2008; Kumar 2012). If an appropriate balance can be achieved, well-developed, sustainable adaptation and mitigation projects can yield additional income for rural development, improved biodiversity and environmental services, support for indigenous communities, and many other benefits (Canadell & Raupach 2008).

Due to the diversity of ecological, political, and socio-economic conditions in the AP, the effectiveness of climate change mitigation strategies is context dependent (Bustamante *et al.* 2014; Innes *et al.* 2009; Ma 1999). As such, no single approach can be developed that will be successful under all circumstances, as the most effective management approach will be chosen based on the anticipated changes in a particular region, the management objectives of a particular forest, local socio-economic dependence on forest resources, and a range of other factors (Innes *et al.* 2009; Ogden & Innes 2009). Generalized sustainability and mitigation criteria are useful in guiding the development and implementation of context-specific mitigation measures (Bustamante *et al.* 2014). Mitigation strategies, particularly those developed at a national or international level, need to be flexible enough to account for site-specific conditions and requirements (Bustamante *et al.* 2014; Innes *et al.* 2014), and not hinder efforts related to maintaining or improving livelihoods in local communities. Additionally, planning and decision-making needs to shift from traditional backward-looking practices to forward-thinking strategies based on forecasting future changes in climate, the associated vulnerabilities, and impacts on forest ecosystems under an array of possible climate and management scenarios (Ahmed & Suphachalasai 2014). This change in perspective is also necessary to understand future forest ecosystems, changes in abiotic and biotic relationships, and the altered physiology of tree species that will undoubtedly result from climate change (Innes *et al.* 2009).

Effective policy for forest adaptation to climate change must account for the uncertainty associated with climate change and consider the interconnected nature of forests with socioeconomic systems (Ogden & Innes 2009). The impacts of climate change are so widespread that targeting climate change adaptation in isolation, without including other initiatives currently in place, may lead to failure (Ogden & Innes 2009). As such, climate change-related policy should be implemented into already existing management frameworks and decision-making processes, and should be developed by local stakeholders and managers who understand the objectives, needs, and institutions of the local region (Ogden & Innes 2009).

4.2 Forest management approaches

Sustainably managed forests are likely to perform well under a range of climate scenarios (Ogden & Innes 2009). Therefore, sustainable forest management presents an opportunity to incorporate adaptation strategies that will buffer against the uncertain impacts of climate change and improve the role of forests in climate change mitigation (FAO 2010a; Ogden & Innes 2009). An adaptive management approach should be used to produce robust strategies that are flexible and responsive to new conditions and information (Ogden & Innes 2009). Such an approach combines management, research, monitoring, and the ability to change practices after evaluation of how successfully objectives are being met. It is a systematic approach that allows management to be continually improved and adapted to changing environmental conditions, policy, or objectives (Innes *et al.* 2009). Selecting adaptation strategies that are applicable to a broad range of alternative climate scenarios reduces the risk of maladaptation that may result from rigid frameworks developed for s specific climates (Ogden & Innes 2009).

Although there is substantial information regarding sustainable forest management strategies, potential impacts of climate change on forestry, and adaptation and mitigation strategies, this information is often conflicting or disjunct and presented in isolation from other relevant information. Improvements in policy and management require information to be presented in a clear, straightforward manner that enables decision-makers to make well-informed decisions (Ogden & Innes 2009). Tools that combine climate and environmental data with numerous management options to perform trade-off analyses, as in the previously mentioned FORECAST Climate, LST, and TACA models, can act as decision-support tools for forest managers and policy makers. Employment of these techniques throughout the AP is encouraged to generate an improved understanding of how stand dynamics will be altered under a changing climate (Nitschke & Innes 2008).

Although most AP countries have included sustainable forest management in their forest policies (FAO 2010a), many have not yet integrated climate change strategies into forestry policy and management (Vickers *et al.* 2010). Some initiatives have emerged, with several AP countries making strides towards mitigating carbon emissions from forests and adapting the industry to account for potential climate change impacts. In 2000, China established new forest plantations that allowed for forest regrowth on 24 Mha of land, offsetting 21% of China's fossil fuel emissions for that year (Canadell & Raupach 2008). Additionally, there has been a substantial increase in forested area in India and Vietnam through reforestation and afforestation efforts in recent years (FAO 2010a). However, some countries in the AP are still increasing their rates of deforestation, leading to an overall decline of forested area in the region. The rate of deforestation in Australia accelerated from an annual average of 200,000 ha during the period 2000 to 2005, to 900,000 ha annually between 2005 and 2010, surpassing Indonesia for having the highest gross deforestation rate in the AP (FAO 2010a). The primary driver of deforestation in Southeast Asia is the establishment of cash crop plantations and agriculture. Conversion of forests to agricultural land increased by 1.2% per annum between 2002 and 2007, leading to a decline in the carbon sequestration capacity of the region (FAO 2010a; Silver *et al.* 2000).

The success of many forest management initiatives in the AP is hindered by a lack of good forest governance (FAO 2010a; FGLG 2014). Several countries, such as Lao PDR, Indonesia, Myanmar, Malaysia, and Cambodia, have outlined targets to increase forest cover, yet these objectives remain unmet (FAO 2011b). An increase in robust institutions and policies, as well as the governance and monitoring of policy and management strategies, are necessary to address the future social, economic, and environmental issues associated with a changing climate (FAO 2010a). To achieve this, steps need to be taken to eradicate government corruption and extortion (FAO 2010a), strengthen government coordination within and among countries, and integrate climate change policy with overall sustainable forest management strategies (Ahmed & Suphachalasai 2014). Addressing climate change is a global effort; there must be greater cooperation among countries to promote capacity building, research and development, and information sharing (Ahmed & Suphachalasai 2014) — especially between developed and less developed nations within the AP. Furthermore, regular monitoring, assessment, and reporting of forest area changes must be completed in all countries in order to establish a baseline, determine whether previous efforts have been successful, and allow for the development of improved policy (FAO 2010a).

International Policy Efforts

Several international initiatives aimed at reducing the contribution of forestry activities to GHG emissions, increasing the resilience of forest ecosystems, and adapting forest ecosystems to climate change, have been developed and implemented with varying degrees of success. Numerous strategies have made progress towards the mitigation and adaptation capacity of forests (FAO 2015a; RECOFTC 2013a; UN-REDD 2009a). However, several have faltered due to a lack of legally binding objectives (UNFCCC 2010, 2014h), lack of funding, or the inability of individual countries to govern and enforce the policies (UNFCCC 1998).

5.1 Intergovernmental Panel on Climate Change (IPCC)

The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established the IPCC in 1988 (IPCC 2015). It is an intergovernmental and scientific body, with contributions from thousands of scientists from all over the world and from governments of the 195 member countries (IPCC 2015; Krzyzanowski 2014a). The IPCC does not conduct any research or monitor climate data or parameters. Its role is to review and assess the most recent scientific, technical and socio-economic information relevant to understanding climate change, its potential impacts, and options for adaptation and mitigation (IPCC 2015). Because of its unique structure, the IPCC provides an opportunity to produce rigorous and unbiased information to decision-makers (IPCC 2015).

The IPCC regularly delivers comprehensive scientific reports about global climate change, called Assessment Reports (AR). The first AR in 1990 stressed the importance of international cooperation to address climate change, and led to formation of the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC 2015). The most recent of these reports is AR5, delivered in four parts between 2013 and 2014 (IPCC 2015). These reports include a chapter dedicated to agriculture, forestry and other land use (AFOLU), with AR5 stressing the mitigation potential of AFOLU activities (Smith *et al.* 2014). The IPCC plays a crucial role in supplying accurate information regarding climate change in the AP, as well as the rest of the world. As such, the organization was awarded a Nobel Peace Prize in 2007 for building a foundation upon which actions can be taken to address climate change (IPCC 2015).

5.2 The United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC is an international treaty established in 1992 to stabilize atmospheric GHG concentrations at a level that will prevent dangerous anthropogenic interference with the climate system and limit global temperature increases (UNFCCC 2014a). Climate change poses not only environmental problems, but will also impact global issues such as poverty, economic growth, resource management, and sustainable development. The UNFCCC aims to be a platform to bridge the gap between all of these issues in order to generate solutions from all disciplines and fields of research (UNFCCC 2014a).

Article 4 of the Convention outlines the commitments of Parties, focusing on reducing emissions as the key element to combatting climate change. Section 4.1.c. calls for parties to develop "...technologies, practices and processes that control, reduce or prevent anthropogenic emissions not controlled by the Montreal Protocol in all relevant sectors..." (UNFCCC 1992, p.10) including forestry. As such, the

UNFCCC applies to carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), and tetrafluoromethane (CF_4) (Krzyzanowski 2014a). Additionally, Section 4.1.d commits parties to sustainable management and promotes the conservation and enhancement of GHG sinks and reservoirs such as forests and biomass (UNFCCC 1992). Furthermore, the convention acknowledges the global imbalance in adaptive capacity and commits developed countries to assist developing countries that are particularly vulnerable to climate change (UNFCCC 1992). The Convention indicates characteristics of countries to which this relates, including "countries with arid and semi-arid areas, forested areas and areas liable to forest decay" (UNFCCC 1992, p. 15).

Today, 195 countries have ratified the UNFCCC (UNFCCC 2014a). However, the convention itself is not legally binding, as it only encourages countries to act on the outlined commitments (UNFCCC 2014b). Several legally binding agreements and adaptations to the Convention have emerged since the UNFCCC's inauguration to increase the likelihood of successfully stabilizing GHG emissions and avoiding catastrophic climate change.

5.2.1 Kyoto Protocol

The Kyoto Protocol was the first legally binding agreement to emerge from the UNFCCC. It was drafted in 1997 to aid Parties in achieving the Convention's principles by outlining the details of mandatory emissions reductions for developed countries, and describing means to achieve these targets (Krzyzanowski 2014a; UNFCCC 2014b). Although it was adopted in 1997, the Kyoto Protocol was not brought into action until 2005 (UNFCCC 2014b) and has since failed to be well accepted or enforced. The goal for the first commitment period (2008 to 2012) was to reduce emissions among Annex I Parties (those considered to be industrialized nations) to 5% below 1990 levels by 2012. The second commitment period (2013 to 2020) aims for a reduction of GHG emissions by 18% below 1990 levels by 2020 (UNFCCC 2014b). Annex I parties in the AP region include Australia, Canada, Japan, New Zealand, and the United States of America (UNFCCC 1998). Parties can meet these targets individually, or jointly by transferring excess reduction units from one Party to another (UNFCCC 1998). This allows some signatories to maintain or even slightly increase their emissions over the 1990 base levels, while still achieving an averaged of 5% reduction among all Parties (Krzyzanowski 2014a).

Changes in a country's GHG emissions due to alteration of sources and sinks through anthropogenic land-use changes and forestry, including afforestation, reforestation, and deforestation, are included in calculations for emissions reductions targets (UNFCCC 1998). This is an important consideration, as there is a substantial difference in GHG emissions with and without the consideration of emissions from land use, land-use change, and forestry (LULUCF) activities (Krzyzanowski 2014a). However, Article 3.7 states that Parties whose land-use changes and forestry activities contributed to a net source of GHG emissions could establish their 1990 baseline values to include LULUCF emissions (UNFCCC 1998). As such, nations could show a reduction in emissions simply by reducing land conversion, rather than industrial emissions. Furthermore, exempting forestry emissions from the baseline calculation substantially increased the baseline value, making it easier to show emissions reductions (Krzyzanowski 2014a). Australia was the only Annex I country for which Article 3.7 applied, as they were the only developed country with significant GHG emissions from land conversion in the 1990 base year. However, Australia did slow its rate of land clearing and conversion, and its forests became a net sink by 2009 (Krzyzanowski 2014a). Comparatively, the inclusion of LULUCF emissions for New Zealand and Canada increased emissions for these countries, with their forests representing a net source of GHG emissions in 2009 compared with 1990 (Krzyzanowski 2014a).

Non-Annex I countries (considered "developing" at the time of ratification) must participate in the Kyoto Protocol through the Protocol's Clean Development Mechanism (CDM). Non-Annex I Parties in the AP region include Bangladesh, Bhutan, Cambodia, China, Republic of Korea, Fiji, Georgia, India, Indonesia, Lao PDR, Malaysia, Maldives, Philippines, Samoa, Thailand, and Vietnam (UNFCCC 2014c). These countries must track and report GHG emissions, but are exempt from meeting set emissions reductions targets. Parties can implement emissions reduction projects, such as reforestation and afforestation, to earn Certified Emissions Reduction (CER) credits that can be sold to Annex I countries to contribute to their emissions reduction targets (Krzyzanowski 2014a; UNFCCC 2014d). However, credits are awarded to project developers, as opposed to the national Parties, which reduces the incentive for non-Annex I countries to develop national forest policy strategies that would earn them CER credits (Krzyzanowski 2014a). Furthermore, the strict conditions and complex processes of implementation limit participation in CDM (FAO 2010a). Of the 2100 registered CDM projects as of March 2010, only 13 involved afforestation or reforestation (FAO 2010a). Six were from AP countries, namely China, India, and Vietnam, which already had substantial afforestation and reforestation initiatives in place without the support of CDM (FAO 2010a).

Although all Annex I countries in the AP are Parties to the UNFCCC, New Zealand is the only country currently committed to the Kyoto Protocol. Australia and the USA withdrew from the protocol before it was initially ratified in 2005 (UNFCCC 2014c). However, Australia finally ratified the Protocol in 2007, and has committed to the second phase targets (Department of Foreign Affairs and Trade 2015). The USA, however, has never ratified the agreement. Canada withdrew from the Protocol in 2012, as the government made minimal efforts to reduce emissions (Doelle 2012; Harrison 2007) and the country was not prepared to spend the money to purchase the international credits required to meet the reduction targets from the first phase (Environment Canada 2013). The Canadian government was also of the opinion that the protocol was ineffective and failed to meet the real challenges of climate change, as it only pertained to a small portion of emitters (Environment Canada 2013). Japan was committed to the Protocol's first phase, but withdrew prior to commencement of the second phase, indicating similar concerns to Canada's—that the framework did not serve their national interest or help address climate change, and that due to the exemption of large emitters such as China and the USA, it was an "unfair and ineffective framework" (MOFA 2010). Despite each county's reasons for not committing to Kyoto, some have attributed the abandonment by Canada and the initial objection by

Australia and the USA, to the influence of the oil industry on government (Crowley 2007; Doelle 2012; Harrison 2007).

By 2012, 30 of the 192 ratified countries had met or exceeded the emissions reduction target of 5% below 1990 baselines for the first commitment period, with Japan being the only country in the AP to do so (UNFCCC 2014e). All other AP countries increased their emissions from 1990 to 2009 (Krzyzanowski 2014a). Failure to meet the outlined objectives may be attributed to narrow-minded, short-term interests of governments and industry (FAO 2010a). The 18th Conference of the Parties (COP18) in Doha, Qatar in 2012 launched the beginning of the second commitment period following the adoption of the Doha Amendment to the Kyoto Protocol. This included new commitments from Annex I Parties, addressed issues that arose during the first commitment period, and revised the list of GHGs that Parties needed to report. The only countries within the AP to uphold these commitments are China, Bangladesh, and Indonesia, none of which are Annex I countries (UNFCCC 2014f). As such, the Kyoto Protocol has lost its relevance to AP nations and their strategies to act on climate change.

5.2.2 Copenhagen Accord

At the Conference of the Parties (COP15) in 2009, the UNFCCC developed the Copenhagen Accord with the objective of keeping the global temperature increase below two degrees Celsius (UNFCCC 2010). To achieve this, countries put forward their own targets for emissions reductions by 2020 (Krzyzanowski 2014a), which differed in base year and target value according to individual socio-economic situations and justifications (Glomsrod *et al.* 2013; UNFCCC 2014g). AP countries that pledged to the Accord include Australia, Bhutan, Canada, India, Indonesia, Japan, Maldives, New Zealand, Papua New Guinea, Republic of Korea, Singapore, Thailand, and the USA (UNFCCC 2014g). Several countries that withdrew or were exempt from Kyoto, such as Australia, China, and India, have made commitments to reduce emissions under Copenhagen. However, the Copenhagen Accord differs from the Kyoto Protocol in that it is not legally binding.

5.2.3 Cancun Agreement

The Cancun Agreement was produced out of COP16 in 2010. It aims to strengthen the global framework for addressing climate change by collectively addressing long-term challenges and taking steps towards a global response (Krzyzanowski 2014a; UNFCCC 2014h). A main objective of the agreement is to "protect the world's forests which are a major repository of carbon", especially in developing countries (UNFCCC 2014h). It also includes discussion of LULUCF, seeking broader agreements to include carbon sources and sinks from forests in developing nations (Krzyzanowski 2014a). The objectives of LULUCF agreements are vague however, and lack discrete targets and dates. For example, countries are required to reduce GHG emissions "as early as possible" (PWC 2011, p. 2). Additionally, it is not legally binding, but instead is intended to act as a framework for a future legally binding agreement. As such, some called into question the effectiveness of such a document in achieving the goal of limiting warming to two degrees Celsius (PWC 2011; The Climate Institute 2010). However, this agreement represents great progress in global collaboration and effort to address climate change, and was an important step towards improved communication between nations.

No legally binding agreement has emerged from the Cancun Agreement framework to date. Instead, the notion is continually pushed to a later date as Parties repeatedly plan and outline vague objectives to which none of them can be held responsible. The current objective is to establish a legally binding agreement at COP21 in Paris in December 2015 (UNFCCC 2014i).

5.2.4 REDD+

REDD+ refers to a collaborative programme developed by the UNFCCC that aims to create a financial value for carbon stored in forests, providing an incentive to reduce deforestation and land degradation in developing countries in order to maintain forest carbon stores (UN-REDD 2009a). REDD stands for Reducing Emissions from Deforestation and Forest Degradation, with REDD+ going beyond deforestation and forest degradation to include the role of conservation, sustainable forest management, and enhancement of forest carbon stocks (UN-REDD 2009a). The basis of REDD+ is to financially compensate forest owners and other involved parties for any financial losses they accrue as a result of preserving forests by foregoing any development or land-uses that involve deforestation (FAO 2010a). Additionally, strategies to reduce emissions from forested lands are promoted as a means to stimulate responsible and sustainable land management and use, enhance forest carbon stocks, and conserve forest ecosystems (IISD 2013; RECOFTC 2014; UN-REDD 2009a). It is estimated that forests sequester over a quarter of global annual carbon emissions (FAO 2011a). As such, REDD+ represents a mechanism for mitigating climate change through carbon sequestration in living biomass rather than through the reduction of anthropogenic emissions (Krzyzanowski 2014a). Countries undertaking REDD+ need to develop national strategies and action plans, a national forest monitoring system to report REDD+ activities, a system to provide information on implementation and compliance of strategies, and determine national forest emission levels (FAO 2011a).

REDD+ in the Asia-Pacific

With 18.3% of the world's forests located in the AP (FAO 2010a) and with these forests contributing a large portion of global GHG emissions (ADB 2009), REDD+ initiatives present an important economic opportunity for AP nations (Krzyzanowski 2014a). Several governments have begun to recognize the importance of REDD+ as a means to generate climate mitigation policy and income for their nations (FGLG 2014; Krzyzanowski 2014a). Additionally, the programme has brought attention to the role of forests in contributing to, and potentially mitigating, the effects of climate change (Nhantumbo 2014). Several AP countries, including Bangladesh, Cambodia, Indonesia, Papua New Guinea, the Philippines, Solomon Islands, Sri Lanka, and Vietnam, receive direct support for their National UN-REDD+ Programme, such as assistance with implementation of REDD+ and the development of National REDD+ Strategies. However, other partner countries, such as Lao PDR, Nepal, Malaysia, and Myanmar, only receive targeted support for national action from the UN-REDD Global Programme (UN-REDD 2009c).

Several countries have formulated action plans and policies to stimulate REDD+ activities. Vietnam incorporated REDD+ strategies into three of their major national forest policies to help modernize forestry in order to improve environmental protection and reduce poverty (Pham *et al.* 2012). Vietnam also developed a National REDD+ Policy for 2011-2020 aimed at capacity building, the development of relevant organizations, and implementation of pilot site projects. Nationally, payments are made for increasing forest carbon stock, reducing emissions, conserving the carbon pool, and sustainable forest management practices (Pham *et al.* 2012). Across the region, several initiatives not directly related to REDD+ have generated a foundation from which REDD+ policy can be developed. These initiatives include forest conservation, land use policy with environmentally sustainable objectives, and forest certification programmes (Brockhaus *et al.* 2014). For example, policies in Vietnam that require payments for environmental services have enabled REDD+ policy development (Brockhaus *et al.* 2014). Vietnam's National Climate Change Strategy was developed to assess the country's response to climate change and requires the National REDD+ Programme to be based on, and in line with, the goals and objectives of this overarching document (Pham *et al.* 2012).

In Indonesia, forests are the foundation of the country's climate change adaptation and mitigation strategies. This was the first country to adopt a legal framework for REDD+ initiatives (Vickers *et al.* 2010) and several REDD+ pilot projects have since been established (Myers 2009; UN-REDD 2009b). Under REDD+, Indonesia has stated that it will increase carbon stocks in forest biomass to 1990 levels by 2030. This will be done through reforestation, afforestation, planting production forests, and restoring production forests using enrichment planting, as well as an improved effort to reduce illegal logging by 43% (Indrarto *et al.* 2012). The Indonesian government has received international support to achieve REDD+ initiatives. This includes the Forest Governance and Multistakeholder Forestry Programme (2007-2010) with the British Government, technical cooperation between Malaysia, Indonesia, and Brunei Darussalam in implementing the Heart of Borneo Initiative (2008-2011), the Kalimantan Forests and Climate Partnership (KFCP) (2009-2012) with Australia, among many others (Atamadja *et al.* 2014; Indrarto *et al.* 2012). Although not all of these initiatives have met their objectives, such as KFCP, they have provided insight into how to improve future efforts (Atamadja *et al.* 2014; Myers 2009; Rosenberg & Wilkinson 2013).

Nepal has also taken steps to pursue REDD+ initiatives, although success so far has been limited. This is partially due to the detachment of these initiatives from the complex dynamics of deforestation, lack of attention to governance issues, and avoidance of issues related to resource conflicts (Paudel *et al.* 2013). Nepal has revised its forest governance framework to accommodate components of REDD+, such as carbon trade. However, this may actually undermine the country's recent progress towards community tenure rights and forest tenure security, threatening the vitality of local forest communities

(Bastakoti & Davidsen 2014). Although REDD+ strategies are encouraged and pursued in Nepal, it has been noted that conservation and carbon sequestration approaches to forest management need to work in balance with the local livelihoods dependent on subsistence activities and forest-based incomes (Kumar 2012).

Overall, the success of implemented REDD+ policies and programmes is variable throughout the AP, and multiple financial setbacks have occurred (e.g. Paudel *et al.* 2013; Pham *et al.* 2012). Governments have been held up by the ambiguous differentiation between UN-REDD (the UN collaborative initiative on REDD, which is meant to act as a blueprint to support national and international REDD+ implementation) and the National REDD+ Programme and uncertainty about which they should follow first, leading to reduced commitment among stakeholders (Pham *et al.* 2012). Uneven adaptive capacity across the region causes some countries to struggle with limited credible data, inadequate availability of qualified personnel, and a lack of information for stakeholders regarding sustainable forest management initiatives (FGLG 2014). Factors such as the absence of policies or failure to implement them, ineffective cross-sectoral coordination, as well as conflicting policy (such as tax exemptions for pulp and paper industry development in Indonesia) have also hindered successful development and implementation of REDD+ initiatives (Brockhaus *et al.* 2014). Political and institutional environments need to be improved in order for REDD+ programmes to succeed, particularly in countries with high levels of deforestation and degradation (FAO 2010a).

Moving forward with REDD+

REDD+ has been recognized at several Conference of the Parties (COP) events. COP13 first put forward the initiative to reduce emissions from deforestation in developing countries (UNFCCC 2008), with successive events providing guidance and frameworks for Parties to take action. Guidelines for activities to reduce emissions from deforestation and forest degradation, as well as information on sustainable forest management and improving forest carbon stocks in developing countries, were addressed in the decisions made at COP15 (UNFCCC 2010). Recently, the Warsaw Framework for REDD+ was developed out of COP19 in 2013 (RECOFTC 2014; UNFCCC 2014j). This framework acknowledges that each country is unique in its circumstances, capacities, and capabilities to address the drivers of deforestation and forest degradation, and that these activities can have many causes. Based on this notion, seven decisions were outlined to provide guidance to parties to develop REDD+ programmes. For instance, all REDD+ countries are required to produce development plans to facilitate the creation of a supportive domestic policy infrastructure, particularly in developing countries. International collaboration during the assessment process is encouraged between Annex I and developing countries to allow developing countries to gain experience in the auditing and review process. Countries are also required to perform internal reviews of national reports to proactively remedy concerns and more effectively interact with external reviewers (RECOFTC 2014). Parties are encouraged to take action to address drivers of deforestation and forest degradation, and increase support for action related to mitigation of climate change in the forest sector of developing countries (UNFCCC 2014k). Overall, this framework has made the process of REDD+ implementation and performance assessment clear and predictable, and should improve the ability of countries to assess capabilities and facilitate the transfer of skills and knowledge through international collaboration (RECOFTC 2014).

Although the progress made at COP19 should begin to increase the success of REDD+, there remains much room for improvement. REDD+ needs to be viewed in a broader context, not solely as a connection between forests and climate change, but as a multi-purpose platform to address numerous drivers of climate change, with numerous benefits that include integrated land use issues (Nhantumbo 2014). Governments need to provide stronger leadership by developing clear policies and regulations that provide guidance to participants on how to reduce emissions from land use change, as well as ensure the enforcement of initiatives. Greater effort is needed to ensure coordination between resource sectors beyond forestry with planning and financial institutions, and to clarify responsibilities of all parties involved (Nhantumbo 2014). Technological developments, such as those mentioned in Section 3, need to be incorporated into REDD+ initiatives to ensure accurate measurement of carbon storage and successful implementation of programmes.

5.3 Regional Community Forestry Training Center for Asia and the Pacific

The Regional Community Forestry Training Center for Asia and the Pacific (RECOFTC) is one of several international organizations working to improve the health and vitality of AP forests and the lives of people who depend on them. It involves government, non-government organizations, and the private sector in its mission to improve policy, institutions, and forest management (RECOFTC 2013a). This organization aims to increase sustainable forest management, improve governance, and generate fair benefits for local people in the AP region in order to reduce forest-related conflicts, improve rural livelihoods, protect the environment, and address climate change (RECOFTC 2011; RECOFTC 2013a). It focuses on using community forestry and community-based forest landscape management to improve forest conservation and restoration, as well as reduce forest loss and degradation (RECOFTC 2013a). Independent reviews have commended RECOFTC’s ability to meet objectives and successfully make relevant, influential change in the AP (RECOFTC 2013a).

Recently, RECOFTC has focused on strengthening local people’s engagement in forests and improving their capacity to mitigate and adapt to climate change. This is being achieved through the development of incentives and rewards for people who maintain ecosystem services in forests and improve adaptive capacity of communities through proper management (RECOFTC 2013b). To gain national and regional support for forest-based mitigation and adaptation to climate change, RECOFTC has generated projects to increase adaptive capacity, highlight the role of community forestry in climate change mitigation, and encourage policy-makers and governments to recognize the relationship between forests and climate change (RECOFTC 2013a). In addition to working with communities and governments to address issues regarding climate change and forestry, RECOFTC also monitors related initiatives throughout the AP (RECOFTC 2013b) and produces research papers and publications on a variety of topics. Topics include the potential impacts of climate change on forests, the success of current management strategies throughout the region, and analyses of the current state of policy, development, and management with respect to forests in the region (i.e. REFOFTC 2012a; RECOFTC 2012b; RECOTC 2014).

5.4 Food and Agriculture Organization

The Food and Agriculture Organization (FAO) was established as a United Nations organization in 1947. The organization has several main objectives, one of which focuses on making forestry more productive and sustainable for current and future generations (FAO 2015a). The work done by FAO is generally global in focus, but there has been considerable effort made to bring attention to long-term pursuits of sustainable forest management in the AP in the face of climate change (FAO 2015a).

FAO's work is multifaceted and dynamic. It includes the dissemination of knowledge, as well as the collection, analysis, and publishing of data and information to aid decision-makers and managers in transitioning to more sustainable management practices (FAO 2015a, b; Ma 1999). A key element of FAO's contributions is a strong relationship with government bodies and policy makers. The FAO acts as a platform for international collaboration and is actively involved in the planning and drafting of policy, helping to ensure adequate financing and structure are in place for successful implementation of initiatives (FAO 2015a, b). Additionally, FAO aims to support countries in preventing and mitigating risks to resources such as forests, and coordinate disaster response plans when necessary (FAO 2015b).

The FAO is a leading source of information for climate change and forestry-related issues in the AP. Their bi-annual (sometimes annual) report, *State of the World's Forests,* highlights key issues concerning forests and any recent policy and institutional developments, with some sections devoted to activities in the AP (FAO 2014). Specific regional and sub-regional reports for and within the AP provide comprehensive information on the current state of forests and the forestry industry in the region, as well as how they are expected to fare under changing socio-economic and environmental conditions (FAO 2010a, 2011b). These documents are important sources of current research, data, statistics, as well as policy-relevant information that facilitate discussion and decision-making. The FAO is therefore an essential resource for an improved understanding of the potential impacts of climate change on AP forests and the development of well-informed sustainable management strategies.

5.5 Center for International Forestry Research

The Center for International Forestry Research (CIFOR) is an international research organization focused on addressing and understanding the challenges of forest and landscape management. Through collaboration with policy makers, managers, and communities, CIFOR aims to protect the environment and improve human wellbeing by developing management and policy decisions based on sound science

(CIFOR 2014). Research emphasis is placed on climate change, forest management and policy, and has produced numerous research papers and reports on these topics for the AP region (i.e. Atmadja *et al.* 2014; Comas *et al.* 2015; Sunderlin *et al.* 2014).

Recently, CIFOR released a web-tool called the Forest Carbon Database (FCDB) to share data on global forest carbon pools. Information is available for seven locations in the AP region (CIFOR 2015). The data are intended to support initiatives that track GHG inventories, provide reference forest emissions levels, and encourage monitoring and reporting of emissions from forestry activities (CIFOR 2015).

Gaps in Adaptation and Mitigation Capacity

The adaptive capacity of a country is influenced by its economic, social, and human development, which in turn are dependent upon factors such as income, poverty, government capacity, availability of education and health services, and economic diversification, among others (ADB 2009). These factors vary between countries in the AP, resulting in a substantially varied capacity to adapt to and mitigate climate change. A lack of legislation and scientific knowledge constrains climate change adaptation in both developing (Begum & Pereira 2013) and developed countries (Ford *et al.* 2011; Milfont 2012), as decision-makers are faced with many uninformed options, making it challenging to develop an appropriate forest management policy (IPCC 2013, 2014). These gaps should be addressed by encouraging strong, sustainable growth that is inclusive of all social classes (ADB 2009).

Sharing information and research among nations can be very beneficial, but to be effective requires a high quality information base consisting of up to date climate data, decision-support tools, regionally downscaled models, and guidelines for assessing climate risks and implementing sustainable management strategies (Ahmed & Suphachalasai 2014). The development of practical and well-developed policy and forestry practices requires timely and accurate forest and climate change research (FAO 2011a). Since technology and research vary greatly throughout the AP region, the more developed AP nations, as well as the international community, need to facilitate the transfer of technology, knowledge, resources, and in some instances, funding, to countries with a lower adaptive capacity (ADB 2009; Ahmed & Suphachalasai 2014). Recent technological advancements, mentioned in the above sections, have improved the capacity of this region to cope with climate change. However, there is much room for improvement, particularly in areas that are impoverished, lacking government and institutional structure, or have been identified as extremely vulnerable to climate change (ADB 2009; FAO 2011a). Furthermore, the dissemination of knowledge to a range of stakeholders at multiple levels (i.e. national, local) will help to achieve a more unified understanding of the potential impacts of climate change (FAO 2011a), and allow each party to develop the best possible strategy for adaptation and mitigation.

Improvement of adaptive capacity in the AP will require integrated effort from multiple levels of government and society in order to fill knowledge gaps, generate incentives for sustainable and adaptive management, and dedicate resources to improved research and technology (ADB 2009). National forest policies may require revision, particularly in countries that have not recently updated their forest policies and laws (i.e. India, Philippines (Yasmi *et al.* 2010)). It is important for national policies to integrate climate change strategies with national and international forest management objectives and commitments (FAO 2011a). There is a need for improved institutional frameworks and cross- and intra-sectoral coordination in order to successfully support the planning, decision-making, implementation, and monitoring of forest and climate change policies (FAO 2011a). Once policy has been developed and implemented, it requires consistent tracking and monitoring of progress and results in order to ensure compliance and achievement of expected outcomes (Ahmed & Suphachalasai 2014).

Education and public awareness regarding climate change and its impacts on environmental and socio-economic factors also play an important role in the adaptive capacity of AP nations. Public awareness regarding the impacts of climate change on forests varies throughout the region (Mortreux & Barrett 2009; Schulte & Miller 2010; Wang *et al.*, 2015), but increased awareness of climate change impacts is positively related to risk perception (Schulte & Miller 2010). Understanding the risks and generating consensus on the need to act will improve engagement of stakeholders and strengthen partnerships between institutions, as well as nations (ADB 2009). Due to the variety of social and cultural associations with forests and the variation of projected impacts, education and awareness initiatives will be more beneficial if targeted to specific communities and economies. This is particularly true for forest dependent people, whose lack of access to information in the past has led to insufficient awareness of the ecological requirements and management practices required to adapt to climate change (FAO 2012).

Future Directions and Recommendations

An increase in locally specific research and species models is necessary for an improved understanding of the impacts of climate change on forest ecosystems throughout the AP. The availability of regionally downscaled models has been shown to substantially increase research related to climate change and forests in British Columbia and western North America, as was the case after the development of ClimateBC (Wang *et al.* 2006) and ClimateWNA (Wang *et al.* 2012). A similar trend is expected to occur in the AP after the introduction of ClimateAP. Tools of this nature increase the availability of information to a wide range of stakeholders and scientists, facilitating research, knowledge sharing, and ultimately leading to improved decision-making and management. It is crucial that these types of tools, as well as other locally specific models and research initiatives, be implemented across the AP region. Several of the technological advancements mentioned in this paper can provide the basis for further development in science and technology. Building upon these achievements will require cross-disciplinary and cross-national collaboration in order to incorporate different perspectives and expertise.

The development of national policy frameworks is imperative to facilitate the implementation of appropriate adaptation and mitigation strategies (Ahmed & Suphachalasai 2014). This requires strong institutions, public education and awareness, networks linking regional and local experts, as well as locally appropriate methods for analyzing and predicting the current and future environmental and socio-economic impacts of climate change. Carbon emissions reduction targets can be achieved, as well as other necessary environmental and socio-economic objectives (Innes *et al.* 2014), as long as actions to adapt forests to climate change are consistent with sustainable forest management initiatives.

Acknowledgements

We thank Dr. Shyue-cherng Liaw from National Taiwan Normal University for his valuable comments to this manuscript. This work is based on a research project entitled: *Adaptation of Asia-Pacific Forests to Climate Change,* funded by the Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet) (APFNET/2010/FPF/001).

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投稿日期：104 年 06 月 29 日
修正日期：104 年 09 月 20 日
接受日期：104 年 09 月 20 日