Document No.:
Receiving Date:
(For APFNet Secretariat)

APFNet

Asia-Pacific Network for Sustainable Forest Management and Rehabilitation

COMPLETION REPORT

Adaptation of Asia-Pacific Forests to Climate Change

(Report period: November 1st, 2011 – October 31, 2014)

Faculty of Forestry

University of British Columbia

Jan 10, 2015

BASIC INFORMATION

Project Title(ID)	Adaptation of Asia-Pacific Forests to Climate Change
Supervisory Agency	Canadian Forest Service
Executing Agency	Faculty of Forestry, University of British Columbia
Implementing Agency	Faculty of Forestry, University of British Columbia

Date of Project Agreement: [15/11/2011]
Duration of implementation: [November, 2011 – October, 2014], 36 months(extended by____months, if any)

Total project budget(in USD)	$1,139,200	APFNet assured Grant (in USD)	$1,039,200
Actual project cost(in USD)	$1,039,200	APFNet disbursed Grant(in USD)	$ 925,280

Disbursement Status	Date of disbursement	Amount(in USD)
Initial disbursement	12/11	$382,500
Second disbursement	12/12	$307,250
Third disbursement	02/14	$235,530
Balance to be disbursed		$113,920
Reporting Status	Schedule [1]implementation	Project progress status[2]
First reporting (12/11 - 11/12)	On track	Satisfactory
Mid-term Progress Report (12/11 - 05/13)	On track	Satisfactory
Annual Progress Report (06/13 - 11/13)	On track	Satisfactory
Semi-Annual Progress Report (12/13 - 05/14)	On track	Satisfactory
Annual Progress Report (06/14 - 11/14)	On track	Satisfactory

[1] Schedule [1]implementation status could be on track/behind/ahead of schedule

[2] Project progress status could be ranked as satisfactory, dissatisfactory, moderately satisfactory, moderately dissatisfactory

Project Steering Committee		
Name	**Title**	**Contact Information**
Dr. Hosny El-Lakany	Director for the CIFOR Board of Trustees, Former Assistant Director-General FAO/Head of the Forestry Department	Tel: 604 822 6921 Fax: 604 8228645 E-mail: Hosny.ellakany@ubc.ca
Rod Keenan	Director Victorian Centre for Climate Change Adaptation Research Centre, Department of Forest and Ecosystem Science, University of Melbourne	Tel: 0390358227 Fax: 0393494218 E-mail: rkeenan@unimelb.edu.au
Linda Joyce	Research Project Leader on Climate Change, US Forest Services	Tel: 1-970-498-2560 E-mail: ljoyce@fs.fed.us
Dr. Ir. Hendrayanto	Professor, and Former Dean, Bogor Agricultural University, Indonesia	Tel: + 62 251 8421 355 Fax: +62 251 8421 355 E-mail: hendrayanto@gmail.com
Dr. Awang Noor Bin Abd. Ghani	Professor and Former Dea, Faculty of Forestry, University Putra, Malaysia	Tel: +603-89467197 Fax: +603-89432514 E-mail: awangnoor@putra.upm.edu.my

Submitted by:

Dr. John Innes, Project Leader.

【Signature】

Jan 20, 2015
Tel: 604-822-6761
Fax: 604-822-9106
E-mail: john.innes@ubc.ca

Project executing agency and technical assistance partner			
Function	**Name**	**Title/Unit**	**Contact Information**
Project Management Board	Dr. John Innes	Project Leader/UBC	Tel: 604-822-6761 Fax: 604-822-9106 E-mail: john.innes@ubc.ca
	Dr. Guangyu Wang	Operational Manager/UBC	Tel: 604-822-2681 E-mail: guangyu.wang@ubc.ca
	Dr. Tongli Wang	Technical Manager/UBC	Tel: 604-822-1845 Email: tongli.wang@ubc.ca
	Dr. Nicholas Coops	IRSS Director/UBC	Tel: 604-822-6452 Email: nichloas.coops@ubc.ca
	Dr. Judi Krzyzanowski	Policy Analyst/UBC	Tel: 604-822-5967 Email: judi@krzyzanowski.ca
Technical Assistance Partner	Dr. Qinglin Li	Member/ BC Ministry of Forests	Tel: 250-387-9355; Email: Qinglin.Li@gov.bc.ca
	Dr. Paul Lawson	Member/UBC Research Forests, Canada	Phone: 604-463-8148 Email:paul.lawson@ubc.ca
	Dr. David Peterson	Member/ US Forest Service	Tel: 206-732-7812 Email: peterson@fs.fed.us
	Dr. Xiaoming Guo	Member/Jiangxi Agriculture Uni.	Tel: 0791-3813243 Fax: 0791-3813123 Email: gxmjxau@163.com
	Dr. Liguo Wang	Member/Jiangxi Agriculture Uni.	Tel: 1-317-788-8587 Email: wangliguo0530@163.com.
	Mr. Cao Lin	Member/UBC/PhD Candidate	Tel: 604-827-4407 Email: lin.cao@ubc.ca
	Dr. Craig Nitschke	Member/ University of Melbourne	Tel: +61 3 9250 6855 Email: craign@unimelb.edu.au
	Mr. Haijun Kang	Fujian A&F University	Tel: 01186-13906911854 Email: haijun145@126.com
	Dr. Yongyuan Yin	Member/Environment Canada	Tel:604-822-1620 Email:yongyuan.yin@ec.gc.ca
	Dr. Brad Seely	Member/UBC Faculty	Tel: 604- 822-8958 Email: brad.seely@ubc.ca
	Mr. Futao Guo	Member/UBC Faculty	Tel: 778-558-6788 Email: guofutao.ubc@gmail.com
	Dr. Shouke Wei	Member/UBC/Research Associate	Tel: 604-827-4407 Email: shouke.wei@gmail.com
	Dr. Cheryl Power	Member/UBC Resident Forester	Tel: 604-463-8148 Email: cheryl.power@ubc.ca
	Mr. Yuhao Lu	Member/UBC/Graduate Student	Tel: 778-320-3326 Email: Yuaho.lu@alumni.ubc.ca

Executive Summary

Climate change is one of the most important threats to the capacity of forest landscapes to provide ecological, economic and social services in the Asia-Pacific region. Meanwhile, the potential of forests to mitigate climate change also represents a major opportunity for the forest sector. Forest ecosystems can either serve as a carbon sink or carbon source depending on their level of health and their resilience to climate change. However, there is remarkably little evidence that science-based decision-making processes are being incorporated into forest management practices in the region. As a result, considerable uncertainty exists over management policies aimed at enabling forests and forest-dependent communities to adapt to climate change. The goal of project is to help forest managers and policy makers to develop effective management strategies to maintain resilient forest ecosystems for adaptation to climate change. Specific objectives of the project are to: 1) analyze the knowledge gaps; 2) develop tools and scientific basis; and 3) enhance the network and capacity building.

The project was implemented during the period November 1, 2011 to October 31, 2014. All of the research and associated activities have been completed and some have exceeded the objectives of the project. The major output achievements included:

1) A scientific and a policy review that reviewed the basic science of climate change and what the Asia Pacific region may expect, and accumulated information on various policy measures in the Asia Pacific region that have been implemented to either adapt to, or mitigate, climate change from a forestry perspective;
2) ClimateAP, a high-resolution climate model, which generates scale-free climate data for a large number of climate variables for historical and future periods. It may serve as an essential tool for the entire Asia Pacific region to facilitate and promote climate change related studies and applications in this region;
3) Climate niche models built for five major forest tree species in the region including Chinese fir, Chinese pine, Masson pine, Douglas-fir and Blue gum, and their consensus projections generated for future periods to provide scientific basis for assessing the impact of climate change, identifying the most vulnerable species and populations, and formulating adaptive management strategies;
4) A spectrum of models applied to pilot sites including an evaluation of the long-term impact of climate change on the growth of Chinese fir in Fujian Province using the process-based model (FORECAST Climate), and identification of key indicators of ecosystem services and the development of decision-support tools for evaluating alternative management strategies in the form of an trade-off analysis;
5) A Google Map based web tool to facilitate data access and spatial visualization of climate data and climate niche projections, which will promote information

flow and knowledge transfer from scientists to policy makers and stakeholders; and

6) Workshops, conferences, surveys and extension notes, and a network built comprising scientists, stakeholders and policy makers from China, Canada, USA and Australia to strengthen the project team and to facilitate information sharing and knowledge transfer.

In addition, we have also generated outcomes from extended research work including fire disturbance parameterizations for China's pilot sites and LiDAR implementation in subtropical forests; both have been generating satisfactory results. In total, we have published or submitted 28 papers in scientific peer-reviewed journals.

To further advance the capability of forest managers to promote the management of forest resources in this region, we have applied for a follow-up project to expand and improve upon the research and tools developed from the first phase, and which can be applied to a broader range of ecosystems and associated communities particularly in China and Southeast Asia, where afforestation is active and/or forest ecosystems and dependent human communities are particularly vulnerable to climate change. The output of this project will improve the capacity of local and regional forest managers to develop robust adaptation strategies to address climate change issues in the Asia Pacific region.

CONTENTS

1. BACKGROUND AND INTRODUCTION

1.1 Project context

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), temperatures are predicted to rise an average of 2 to 4°C globally by the end of the century. This magnitude of temperature rise and its associated climatic changes could overwhelm the resilience of even the most adaptable forest ecosystems and threaten their components, including plants and animals. Bioclimate envelopes (suitable climate niches) for the current forest ecosystems and their components, particularly forest trees, are predicted to shift much more rapidly than forest trees can migrate naturally. As a result, some local forest tree species currently occurring in these ecosystems will not be able to adapt to their local environments in the future. This will compromise the productivity and resilience of these ecosystems, and may change the forest landscapes from carbon sinks to carbon sources.

For instance, the 18 million hectares of forests affected in British Columbia by a mountain pine beetle outbreak induced partly by warmer temperature associated with climate change is a good example of what could happen elsewhere. According to the IPCC, ecosystems of the Asia-Pacific region are particularly vulnerable to climatic changes such as temperature and aridity that are expected to increase more rapidly in parts of this region than the global average. Climate change is therefore considered to be the most important threat to the capacity of forest landscapes to provide ecological, economic and social services. Mitigating and adapting to climate change are pressing challenges for the scientific community, stakeholders and policy makers.

The potential for forests to mitigate climate change through carbon sequestration represents a major opportunity for forestry. This is particularly important given the stated policy aim of planting 20 million hectares of forests in this region in the coming years. In establishing new plantations, there is an opportunity to select tree species that match current and future climate conditions in order to avoid maladaptation. Meanwhile, climate change will also bring new opportunities. Some planting sites may become suitable to grow species that grow faster and that are economically more valuable than the current local species.

The appropriate management of existing forests and the planning of the new plantations are critical to the adaptation of forest ecosystems to climate change and to determine the role of forests in mitigation of climate change. However, there is remarkably little evidence of sufficient quality to be incorporated into science-based decision-making and, as a result, there is considerable uncertainty over the most appropriate policies to enable forests and forest-dependent communities to adapt to climate change. In this project, we brought scientists, government officials, forest managers, investors and local communities together to examine the implications of climate change, to develop and utilize essential tools such as high-resolution climate models and sophisticated ecological models for the Asia-Pacific region, and to facilitate information sharing and knowledge transfer. This will ensure the transfer of the scientific knowledge directly to decision-making processes, and enable policy and decision makers to identify adaptation and mitigation strategies to underpin climate change policy.

The project has satisfied the objectives of APFNet by promoting forest rehabilitation, reforestation and afforestation in the region. The project will also strengthen sustainable forest management, improve forest quality in the region, and enhance the productive capacity and socio-economic benefits of forest ecosystems. Meanwhile, project outcomes will lead to enhanced biodiversity conservation and rehabilitation through the developed science-based technologies to determine the impacts of climate change, and by providing strategies for integrating mitigation and adaptation as responses to climate change.

Target Area

The project covered a large proportion of the Asia-Pacific Region (Figure 1.1), the primary focus of APFNet. The pilot study sites were located in western North America, Australia and China. The climate and ecological models covered the majority of the region, including all of western North America, China and Australia. Through technical training and knowledge transfer, the ecological models may be extended to other parts of the region. As a result of the full coverage of the climate models, and the methodologies developed in this project, it will be relatively easy for other countries in this region to develop similar ecological models and to develop effective adaptive strategies.

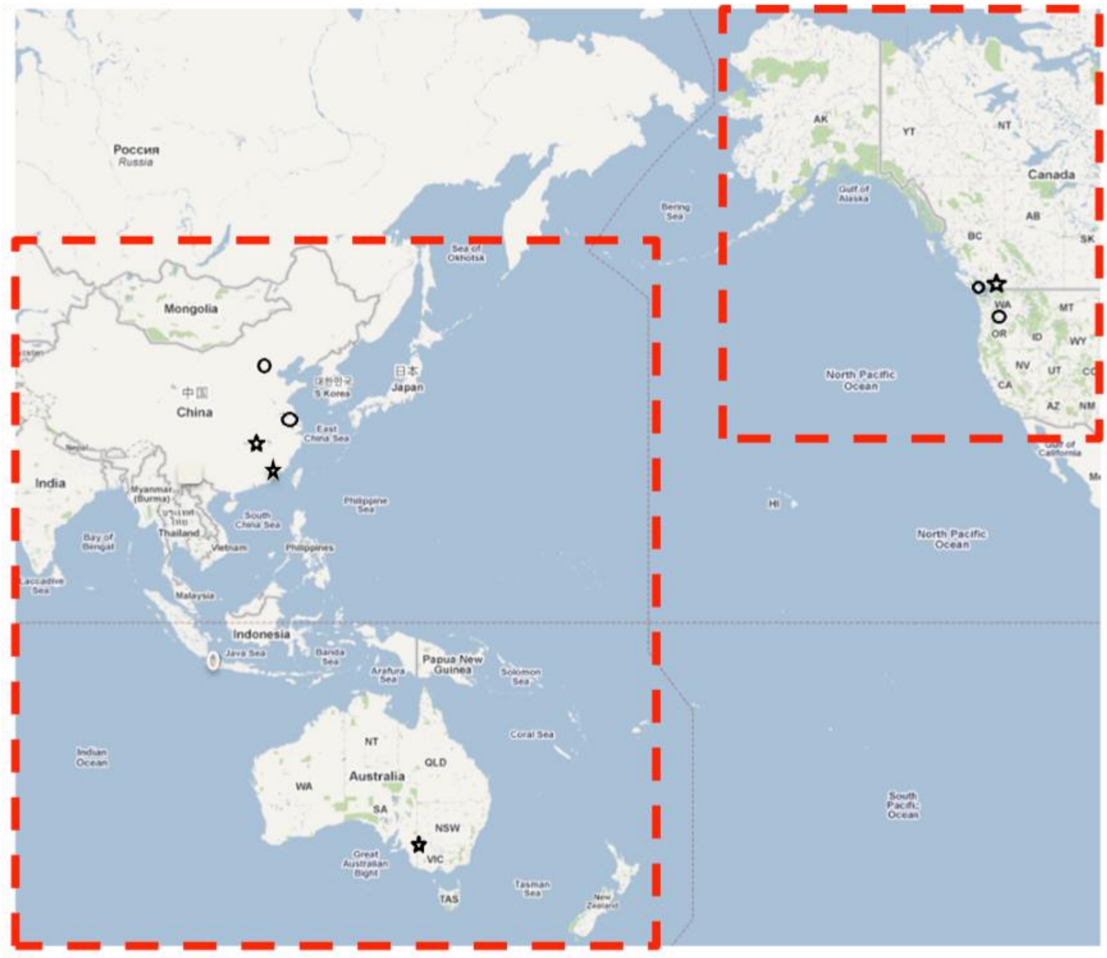

Figure 1.1: The study areas are highlighted by the red rectangles. Climate models covered the entire project areas, while the ecological models were focused on five major trees: Douglas-fir (*Pseudotsuga menziesii)*, Chinese fir (*Cunninghamia lanceolata)*, Chinese pine (*Pinus tabuliformis),* Masson pine (*Pinus massoniana),* and Blue gum (*Eucalyptus globulus).* Pilot experiment sites (stars) and partners (circles) are also indicated on the map.

1.2 Project goal(s) and objectives

A major problem for the forests of developing countries is that very few are managed sustainably. The International Tropical Timber Organization has estimated that only 5% of the forests in the developing countries of the Tropics are managed in a sustainable manner – i.e. such that they continue to supply benefits. As a result, they are failing to achieve their potential in reducing poverty development. The problem extends beyond the developing countries of the tropics, and significant areas of the world's forests cannot be considered to be managed sustainably. Countries such as the Canada, Australia and the USA have the ability to provide the technological expertise that other countries need to manage their forests more sustainably. This project represents an important step in such a process of technology development and transfer.

Beyond the completion of this project, a greater proportion of the forests in the Asia-Pacific region will be managed sustainably, and forest managers will be better able to address climate change and related issues. Moreover, the ecological rewards that result from the implementation of sustainable forest management – such as enhanced biodiversity and reduced carbon emissions – improve forest ecosystems, and their ability to provide a wide range of social-economic benefits for forest-dependent individuals, communities, and civil society.

Achievements of this project are measurable using the following specific indicators:

1) The development of climate models and ecological/bioclimatic models will provide internet-based datasets to forest managers and practitioners, as well as guidelines for management plans, such as species selection, prevention of natural disasters, risk avoidance, and so on. This, in turn, will enhance their capability to maintain viable businesses. This use of this information (quantified via web hit counts etc,) will indicate the success of this extension activity.

2) The establishment of a knowledge pool (including the project website) related to climate change and sustainable forest management issues will communicate the information amongst stakeholders in the Asia-Pacific region. Again website usage will aid in evaluating knowledge use.

3) The establishment of pilot sites in selected countries (e.g., Canada, the U.S.A., China, and Australia) in the Asia-Pacific region will demonstrate and test “best management practices” associated with SFM and indicate some of the subtleties associated with ecosystem adaption to changing climatic variables.

4) A holistic and comprehensive Criteria and Indicators (C&Is) system has already been established in China, and will provide a frame of reference while taking into account the specific local context. These C&Is are also available for other areas in the region and are associated with certification and other management tools.

5) Acceptance and utilization of the established models in the Asia-Pacific region by researchers, policy makers and managers, will be a sign of success and extend the influence of this project and APFNet to the remaining parts of the world.

6) The creation of better formulated forest-related policies, laws, regulations, and initiatives under uncertain climate conditions, will verify use of the project’s results by government officials to

Objectives:

1) Analysis of the current status of climate change studies in forest ecosystems and forest-dependent communities in this region
2) Development of high-resolution climate models
3) Development of ecological models
4) Development of adaptation strategies in management practices
5) Network building and technology transfer
6) Development of web-based scientific tools

1.2 Project expected outputs and outcomes

Output 1: A report analyzing current knowledge on climate change studies in forest ecosystems and forest dependent communities in this region.

Output 2: High-resolution climate models that can generate climate data for any location in the region for historical years (1901–2010) and future periods (2020s, 2050s and 2080s). High-resolution climate maps will also be provided for some important climate variables, such as mean annual temperature, mean annual precipitation, arid index and growing degree-days, for the entire region. These will serve as essential tools for climate change related studies and applications in this region, and will facilitate a wide range of climate change studies.

Output 3: Ecological models that predict impacts of climate change on major tree species distributions (Chinese fir; *Eucalyptus*; and Douglas-fir). Maps of predicted shifts in suitable climatic conditions for these major marketable tree species will be provided for various climate change scenarios. The models can be expanded to other species in other countries through extension in next phase after the completion of this project. Ecological models and their outputs will provide a fundamental framework for assessing climate change impacts and developing adaptation strategies in forest management practices and species selection. Predicted impacts on these tree species will enhance the awareness of the scientific and forest practitioner communities about the potential changes in climate throughout the region, and how appropriate management can mitigate these effects.

Output 4: SFM recommendations to increase the resilience of forests and forest-dependent communities in the Asia-Pacific region to climate change. These recommendations will be based on predicted impacts of climate change on major forest tree species and interactions between current forest management practices and climate change in different areas. The recommendations will be at different levels including national, regional and local forest policies and plans, and must be consistent with the principles of sustainable forest management while still allowing for changes to occur in many forest processes. Specific recommendations will be provided for the 4 pilot sites that are being used to demonstrate the implementation of the adaptive strategies.

Output 5: A network that connects scientists, forest managers and policy makers in the region to share information, knowledge and new research products. Workshops, field visits and exchange of personnel (particularly from China to western North America) for training and knowledge transfer will be implemented through this network. This network will help decision-makers become more familiar with decision-making processes under conditions of uncertainty.

Output 6: Web-based scientific tools for regional forest rehabilitation and afforestation including interactive climate models, climate maps, bioclimate maps for major ecosystems and some important tree species. These tools will facilitate scientists, stakeholders and policy makers for easy access to up-to-date information and knowledge on climate change in this region.

2. PROJECT IMPLEMENTATION

2.1 Project schedule and implementation arrangements

An annual plan was prepared in advance of each project year based on the proposal schedule. In general, we were able to follow the schedule for each of the major activities in the proposal. Therefore, there were no major changes or project revisions.

To enrich the output of the project, we considered suggestions made at the project inception meeting and integrated them into the project implementation. These suggestions included: 1) adding two major forest species in the niche-based modeling and 2) exploring the impact of climate change on forest fires.

We also encountered some unexpected difficulties in the process of the project implementation. When incorporating IPCC AR5 GCM future climate data, we did not expect the data format to be changed so dramatically and delayed for so long; this made our previous data integration mechanism unusable. We had counted on the Pacific Climate Impact Consortium (PCIC) to convert these datasets, but their output was not delivered when promised (and is still missing). Consequently, we undertook this task ourselves, and successfully incorporated 90 projections from 15 GCMs into ClimateAP.

Fire risk analysis and management have also been listed as important additional research activities, as mentioned above. The inclusion of this research broadened the initial scope of the project. As the occurrence of natural fires at the UBC Research Forest is very low, we adopted a research site in China (Daxing'an Mountains). However, although fires occur frequently in the study area there, we had to collect long term historical fire data.

In addition to the supplementary activities suggested at the inception meeting, we also added several other activities that helped the integration of our planned activities based on the increasing capacity of our research team. These activities include remote sensing, carbon budgets, water stress, LiDAR data and its technology, and particularly systems dynamics modelling. All these activities have generated interesting results, and again increased the initial scope of the project.

2.2 Project resources and costs

There was one funding agreement signed on November 15th, 2011 between the Executing Agency (EA), UBC and the Project Overseer, the Canadian Forest Services. The project implementation period was 36 months. The total fund of the project is estimated at US$2,211,700, among which US$1,139,200 is granted by APFNet, US$1,072,500 was contributed by the EA and TAPs. The project's financial details are listed in Annex B.

UBC developed and implemented effective policies, administrative systems, procedures, and controls to ensure that all activities funded by and the Agency were conducted in compliance with all:

1) Legislated requirements;

2) Agency policies and procedures; and

3) Other agency requirements specific to a particular Grant or Award

The faculties and departments in UBC are required to follow UBC established policies and procedures for the management of grant and award funds. Aside from the UBC policies and procedures, there are also specific human resources, Payment and Procurement, Payroll, Research and Trust Accounting guidelines that they need to abide by.

At the department of Forestry Resource Management, there is a structured workflow to ensure a transaction from initiation to approval and processing is in a proper sequence to ensure they are performed in according to the EA's policies and the Funding Agreement.

Payment made during the fiscal project period 2011- 2014 in the following categories was selected for examination: 1) Operating expenses including remuneration, reimbursement of travel expenses; 2) Research expenses including research supplies and materials. The salary expenses represent over 80% of all reported expenses, and samples of the employees' appointment forms and contract were selected. In addition, these transactions were examined to ensure proper approvals processes were followed, including proper Human Resource approval steps. The travel expenses claimed were examined to ensure they are in compliance with the EA's travel policy.

The research related expenses were examined to ensure the use of the funding is in compliance with the purposes described in the Funding Agreement and the annual work plan. In conclusion, the EA used funding for the purposes intended in the Funding Agreement and Project Proposal.

Budget variances:

Survey / Case study 15% underspent
Website based tools development 29% overspent

Accrued balance has been committed but not yet paid. Challenges to processing payments for international partners have resulted in accruals; however, these funds are committed and will be processed shortly.

As UBC does not permit deficits, the 10% holdback funding has been committed, but we cannot disburse until we receive the holdback funds.

2.3 Procurement and consultant recruitment

All services were performed under approved work plans and were used directly and only by the Project and contributed to the achievement of project goals and objectives.

In accordance with the work plan submitted December 2013, one computer was purchased to manage the data sets required for the project. Goods purchased by funds administered through the Executing Agency (EA), remain the property of the University.

UBC has developed and implemented effective policies, administrative systems, procedures and controls to ensure that all activities funded by and the Agency are conducted in compliance with all:

1) Legislated requirements;

2) Agency policies and procedures; and

3) Other agency requirements specific to a particular Grant or Award

2.4 Monitoring & evaluation and reporting

A systematic and comprehensive approach has been developed and adopted by the Executing Agency (EA) for monitoring, reporting, review, and evaluation in the previous project. There was an annual work plan prepared in advance of a new project year. A semi-annual and an annual progress reports were submitted in the middle and the end of each year, which summarized the work that had been implemented thus far and to evaluate the progress of the project. In addition, a Mid-Term Progress Report for the period from November 1st, 2011 to April 30th 2013.

These summarized the research completed for each output, the results of the application of models/tools, indicated the next steps to be taken for each component, evaluated whether the project implementation was on track, and outlined the actions to be taken for any sections that not had progressed as far as desired. As well, they outlined the additional research that was done beyond the original scope of the project. Frequent communication and interactions with APFNet staff also contributed to ensure the progress on the track.

Several team members also prepared highly detailed reports of their research in the months before the scheduled completion of the project. These reports included technical details of the tools/models they produced, the findings of their research, and the application of their work in the context of this project and beyond. Any persons that were not on track were aided in any way possible to ensure thorough and timely completion of their portion of the project.

There were regular project meetings every two months for team members to report the progress, to discuss issues encountered and to present plans for the next step. Brainstorms were organized for six times during the project period to explore solutions for research problems, particularly on dynamic system modeling and model integrations.

However, we found that it was time consuming to prepare some many progress reports. To our best knowledge, most of the funding agencies no longer require semi-annual progress reports.

In addition to monitoring research related progress, UBC's finances team diligently monitored the project's budget. An Internal Audit Report was completed in March 2014 utilizing UBC's meticulous financial tracking system, which employed strict reporting criteria to evaluate how well the project's budget was controlled. This report aimed to determine whether the UBC had put in place an effective Management Control Framework for the monitoring and compliance of the terms and conditions of the Funding Agreement. This was achieved through a review of the project's proposals, progress reports, and financial reports; interviews with the project's management team, researchers, partner organizations, and accounting officers to evaluate the current practices and controls; and an analysis of data within the department's financial system.

The auditor concluded that UBC had in place an effective financial and research management control framework for the monitoring the use of funding, and that work completed up to that date complied with the UBC policies and procedures, and the terms and conditions of the Funding Agreement. As well, it was identified that the project management team had developed a systematic approach to ensure the successful implementation of the project including reporting, reviewing, monitoring, and evaluation. APFNet was given the final audit report to review while the project was still in progress to ensure the project was on track financially, and that the allocation of funds were to their satisfaction.

2.5 Dissemination and knowledge sharing

The research team organized and participated in several events to share the research and knowledge acquired from the project with the broader scientific community (Table 2.1). Additionally, this project generated three reports (two literature reviews and the final technical report), over 20 publications, and two books, which will facilitate further study on the topic of adaptation of Asia-Pacific forests to climate change.

Table 2.1 A summary of the number events and people involved in network building activities.

Item	Number of Events	Total number of people involved	Duration
Visiting Delegates	12	280	Less than a week
Training and Workshops	4	350	One week
Academic training, graduate students and visiting scholars	6	6	3 months and up
Conferences	7	380	Half day seminars
Seminars	16	860	Half day seminars

The network was built gradually through various activities including events held at The University of British Columbia (UBC), Canada (Climate Change Adaptation - Sustainable Forestry Management Workshop) and in Yichun, Heilongjiang Province, China (International Conference on Response of Forests and Adaptation Management to Climate Change), which were designed for the project, and invited experts from all over the world to discuss the nature of the project and knowledge gaps that may exist. Partnership and collaboration with local people/organizations was an important part of these events. For instance, the event held at UBC was cohosted with Environment Canada – a department within the Government of Canada – and brought together people in Canada and from around the world from various disciplines including forest managers, academics, government employees, and students. The project's achievements that were highlighted were those that pertained to the Canadian forestry industry's needs. This was common to all events attended by team members; although this project covered a large geographic scale, the topics discussed at events focused on project tools and knowledge that were specific to the host location or country, so that participants received the most beneficial information for their unique situation.

Additionally, project team members attended international meetings and conferences such as the Asia Pacific Forestry Commission in New Zealand, the Sustainable Forest Management Conference in Malaysia, and the Ecosystem Services Conference in Costa Rica, where they discussed the project's research as a means of achieving practical solutions to management and adaptation problems, and enhancing ecosystem resilience. Through these events and conferences, the team gained valuable opinions and insight that were used to improve the project. Additionally, team members were able to increase the international awareness of the importance of research on adaptation and mitigation of forests in the Asia-Pacific, and highlight the work being done to improve the regions adaptive capacity.

A training workshop, based on "Strategies and Approaches for Sustainable Management in Changing Climate", was held in Kunming City, China in July 2013 as part of the project's capacity building program. It provided education and training to participants from twelve Asia-Pacific countries regarding effective development and implementation of appropriate management regulations for combating climate change. The workshop was headed by several members of the project, including Dr. John Innes, Dr. Peter Marshall, Dr. Qinglin Li, Dr. Tongli Wang, Dr. Craig Nitschke, Dr. Brad Seely, Dr. Sally Aitken, Jack Woods, and Dr. Guangyu Wang. A freely available training handbook was assembled for participants, summarizing the development, application, and relevance of the models and tools related to sustainable management of forests. Additionally, a report was compiled regarding management and climate change adaptation of forests in participants home countries, further facilitating information sharing among those involved in the project and beyond.

The International Union of Forest Research Organizations (IUFRO) Congress in Salt Lake City was attended by Dr. Tongli Wang, Dr. Craig Nitschke, and Dr. Qinglin Li in October 2014. They each gave presentations on the latest developments of the project related to their corresponding research, which included the use of the model ClimateAP, the impacts of climate change on forests of Southeast Australia, and using trade-off analyses for climate change adaptation. These presentations were well received by participants of the congress and yielded informative discussion on each topic.

Research seminars were conducted at several universities and research institutions to audiences ranging from 50 to 120 people. These events were aimed not just at academic audiences, but also presented to government bodies as a way of connecting them with the research and tools produced by the project, so that they may be aware of the importance and urgency of climate change adaptation and of the tools available for them to act. The research seminars were half-day presentations held in conjunction with other local research presentations. The presentations were targeted towards the local region, with the topics and tools discussed being relevant to the adaptation of the local ecosystems. These events contributed significantly to the project's successful networking, and were an essential means of expanding the scope of the network beyond academic researchers to include government agencies and industry.

Team members participated in 16 seminars over the duration of the project, which benefited approximately 860 participants (Table 2.1). The location of these seminars is as follows: in Malaysia: Universiti Putra Malaysia; in India: Indian Forest Service; in Taiwan: National Taiwan University, National Taiwan Normal University, Taiwan Zhongxing University, Jiayi University, Ilan Univeristy, and the Taiwan Forestry Bureau; in Mainland China: Northwest Agriculture and Forestry University of China, Nanjing Forestry University, Fujian Agriculture and Forestry University, Hebei Agriculture University, Xiamen University, and the Chinese Academy of Forestry; in Australia: University of Melbourne; in Canada: University of British Columbia.

A questionnaire was developed and distributed to experts of various backgrounds on climate change and forestry in the Asia-Pacific. This helped to facilitate the transfer of knowledge in both directions – it made participants aware of the research being conducted by this project, and provided the project's research team with insight into experts' opinions on topics such as the impacts of climate change, the availability and success of actions/policies, challenges for adaptation, and where science and management tools for dealing with climate change are lacking. The results of the questionnaire were then compiled into a paper that has been submitted for publication, which will further disseminate the information provided by the experts.

Along with disseminating knowledge to the scientific community, steps were taken to allow stakeholders, policy makers, forest managers, and the general public access to the work and tools developed by the project through the online modeling tool, and the project website. An online map-based version of ClimateAP is available through the web browser (http://climateap.net/). Through this site, users can generate spatial visualization of climate maps, and spatial projections of climate niches generated by the projects ecological models for different time periods and climate scenarios. The project website (http://asiapacific.forestry.ubc.ca) includes the project's research objectives, research team members, events, and updates on the latest progress of the project. This website will also serve as a gateway for people to access publications related the projects outputs.

3. PROJECT PARTNERES' PERFORMANCE

3.1 Performance of Supervisory Agency (if any)

The APFNet committee successfully fulfilled its role of reviewing and providing feedback on the project's midterm and annual reports. The reviews were timely, detailed, and invaluable for improving the research and the management teams approach to coordinating the project. The Canadian Forest Service acted as the focal point for the project, doing so in a timely and efficient manners, and was very supportive of the project's endeavors. They provided comments and suggestions on the research and outputs, and helped ensure all activities were carried out successfully.

3.2 Performance of Executing Agency

The Faculty of Forestry at the University of British Columbia (UBC), Canada was the Executing Agency for the project. The project management team, Dr. John Innes, Dr. Guangyu Wang, and Dr. Tongli Wang, are all in the Faculty of Forestry at UBC. The EA was responsible for the implementation of the project, financial management, and the coordination of project planners from Australia, China, and Canada.

The project managers successfully fulfilled all their objective, responsibilities and tasks, some of which were even exceeded. They were able to acquire funding and in-kind contribution from other agencies such as Environment Canada (funding and Dr. Yin's in-kind contribution), BC Ministry of Forests, Lands and Natural Resource Operations (Dr. Qinglin Li's in-kind contribution and funding and in-kind research), scientists' contributions from Northwest Agriculture and Forestry University for forest fire related data collection and analysis, in-kind contribution from Fujian Agriculture and Forestry University for Chinese fir data collection and analysis, and also in-kind contribution from Nanjing Forestry University for collecting data for Yushan forest management, significant in-kind contribution from UBC MKRF Research Forest etc., all of which enlarged the project's capacity. The Australian pilot research also received several financial contributions from state and national research funding agencies. The cost of the project was kept within the budget, and in the end extra money was available. The diligence of the research team and additional funding allowed the scope of the project to be increased, and supplementary research activities to be carried out.

3.3 Performance of Implementing Agency (if any), consultants (technical assistants), contractors, and suppliers

The major research activities were conducted by the University of British Columbia the Executing Agency for the project. The collaborators also played important roles in the project. Chinese Academy of Forest helped in coordination of data collection. The researchers and staff at the pilot sites were active and helpful in data collections and involvement of research activities.

3.4 Performance of APFNet

APFNet was very supportive throughout the entirety of the project, and their contributions met and exceeded the expectations of the project's management team. They provided useful feedback on the project planning, and the distribution of funds. This was mainly achieved through refinements to the Annual Work Plan. Grant money was provided in a timely manner. No delay occurred during the entire project period.

There was excellent communication between APFNet and the Faculty of Forestry at UBC. The expectations of both parties were made clear, which enabled the project to be carried out smoothly, and the project's objectives to be successfully met. Project managers met with APFNet representatives in Beijing to discuss the progress and present the project's final report, and were given useful feedback to improve project outputs. As well, Mr. Kebiao Huang's presence at the project wrap up meeting held in December 2014 at UBC was very beneficial in ensuring that this report would meet the expectations of APFNet, and that the project had covered all the key objectives outlined by APFNet.

APFNet provided timely and useful feedback on the project's progress reports. This information was invaluable for improving research strategies, objectives, and focal points.

4. PROJECT PERFORMANCE

4.1 Project achievements

Output 1: Literature Review

A literature review was completed yielding two science review papers – *Climate change and forestry in the Asia-Pacific,* and *Climate change and forest policy in the Asia-Pacific*. This work provided the background for all other project endeavors.

Climate change and forestry in the Asia-Pacific included the fundamental science of climate change, and the impacts the Asia-Pacific may expect with regards to forest structure and function. The goal of the science review was to present an analysis of the current status of climate change studies in forest ecosystems and forest-dependent communities in this region. This was achieved through the examination of patterns of temperature and moisture changes, and the associated impacts on species and range shifts, invasive species establishment and spread, wildfires, and various strategies for forest management. This review then presented tools and practices for forest managers and users throughout the Asia-Pacific region to utilize to mitigate and manage their forest systems in light of uncertainties and challenges.

This review paper revealed unique patterns of climate change and varying impacts across the region, such as temperature and precipitation pattern changes, forest species movement, and changes in abiotic disturbances. The report synthesized existing knowledge on forest processes and their climatic drivers in relation to a changing climate, which has increased the understanding of how changes in these climatic variables will differentially influence ecosystems throughout the Asia-Pacific. Additionally, forest management techniques and the anticipated effects of climate change were investigated for major economic species to understand management methods that may be detrimental to forest ecosystems, and how to improve upon these to ensure high levels of forest resilience to disturbance. The paper identified management strategies to improve the health of forest, and indicated tools, such as the process-based models developed in this project, which managers can use in long-term forestry planning while accounting for the effects of climate change. Overall, forests of the region are faced with increasing temperatures, frequency of catastrophic fires and storms, pest and disease outbreaks, and overall niche or habitat shifts. However, these forests are resilient, and through appropriate management strategies the region's forests can not only aid in climate change mitigation, but also help provide resources for the people that depend on them.

Climate change and forest policy in the Asia-Pacific is a review of various policy measures in the Asia-Pacific region that have been implemented to either adapt to, or mitigate climate change from a forestry perspective. The objective, which was achieved, was to determine whether existing policies could enable the region's inhabitants and forest managers to adapt their practices in order to limit climate change and its impacts on forests and the communities that depend upon them. Additionally this review summarized existing policy instruments used at various scales – global, multi-national, national, and domestic – throughout the Asia-Pacific for climate change mitigation or adaptation as they relate to forests, and of policy instruments used in forest management that relate to climate change.

The review indicated that forest and climate policies are diverse regarding their goals and strategies, as well as their implementation and success. They are often geared to the jurisdiction in which they are developed. Countries efforts to protect forests and reduce greenhouse gas emissions cannot simply be looked at in isolation, as detrimental impacts associated with the extraction of forest resources may simply be outsourced. For forests to contribute successfully to the mitigation of climate change, the large-scale, regional balance will need to be considered to ensure environmental degradation is being reduced and not simply being redistributed throughout the Asia-Pacific. Additionally, due to the diversity of forests throughout the region, forest-based climate change policies must recognize the complexity and heterogeneity of forest functions and processes, and be deeply rooted in science. Policies must also account for the various economies and social differences between and within countries, and be enforceable, yet flexible to changing perceptions and knowledge. Although existing policies appear insufficient in effectively mitigating climate change in the Asia Pacific region, or globally, the integration of scientific research with effective forest management principles will enable the region's inhabitants and forest managers to adapt their practices and limit the impacts of climate change on forest and forest-dependent communities.

Significance of the literature review

These reports highlighted the importance of this project for increasing the potential of the Asia-Pacific region to mitigate and adapt to climate change. They indicated several gaps in knowledge of the impacts to forest ecosystems, as well inadequacies in management and policy for addressing these issues. Many of these shortcomings were then addressed by the project's subsequent outcomes, such as the development of process-based models and interactive web tools to aid in forest management decisions. The comprehensive summary of how environmental factors influence the forest ecosystems in the context of climate change is vital for future research, and the development of tools and models to investigate climate change impacts in the Asia-Pacific.

Output 2: Development of a high-resolution climate model, ClimateAP, and satellite-borne remote sensing datasets.

ClimateAP

The development of ClimateAP successfully met the objective of developing a high-resolution climate model. It is so far the best and easiest to use climate model for generating high-resolution climate data for important climate variables, such as mean annual temperature, mean annual precipitation, arid index, and growing degree-days, for historical years and future periods for the entire Asia-Pacific region. Typically, research scientists have used geographic variables, such as latitude, longitude, and elevation, as substitutes for climate variables in experimental design and data analysis. However, climate is the primary factor regulating the geographic distributions of forest ecosystems and tree species, and the main driver affecting the health and productivity of trees. Employing geographic variables limits the application of models to a specific location. ClimateAP thus utilized climate variables to ensure the model is applicable throughout the region, ensuring that it will be useful in predicting the impacts of climate change.

ClimateAP is unique as no installation or mapping programs/abilities are required. It has a straightforward, user-friendly interface, making it accessible to people of various levels of climate modelling knowledge, allowing it to be used by a wide range of persons, from researchers to policy makers to forest resource managers. Users can easily obtain data for multiple locations and multiple years with a few clicks – a process that requires tremendous amount of time and effort otherwise. ClimateAP generates climate data for specific locations of interest, thus facilitates more accurate model predictions for tree health and productivity than previous models, leading to more useful climate maps than ever before. This will help develop more targeted and effective management strategies to deal with climate change at any location throughout the Asia-Pacific region.

ClimateAP can be used for climate based experimental design, modelling climate niches for ecosystems and species, and population responses to climate. The outputs can be imported in ArcGIS to generate high-resolution climate maps. Those produced for specific areas are particularly useful for developing management strategies accounting for changing climate conditions, and will benefit forest managers and resource planners.

Significance of ClimateAP

ClimateAP is an invaluable tool for climate change research. It can be applied to any location in the Asia-Pacific, and is the best tool for generating high-resolution climate data, which should help satisfy the increasing demand for this type of spatial climate data. Its high accuracy will help building ecological models to generate more useful predictions regarding the impacts of climate change, yet it is simple enough that it can be used to persons of various levels of modelling knowledge. This will in turn allow for the development of more successful policy and forest management strategies. ClimateAP will serve as an essential tool for climate change related studies and applications, providing a means for researchers and forest managers to project potential changes in climate for their region. It will facilitate a wide range of climate change research, and the development of adaptation and mitigation strategies for crucial forest ecosystems throughout the Asia-Pacific region.

Remote Sensing

This project utilized Normalized Difference Vegetation Index (NDVI) datasets in conjunction with climate data to understand how vegetation dynamics (i.e. annual productivity, seasonality, and the minimum amount of vegetated cover) respond to climate change. Studies were conducted for the Asia-Pacific region as a whole, as well as with a focus on China. This involved investigating the spatiotemporal changes in both trends of vegetation dynamic indicators and climatic variables, as well as their relationship with land cover.

This technology generates greater understanding of how changing climatic conditions influence the productivity of vegetation, and how this varies between ecosystems. Investigating the correlation between NDVI anomalies and climatic anomalies determines if there is a relationship between these factors, and how that relationship varies between land-cover types and geographical location. NDVI data can be mapped to easily visualize changes in vegetation growth dynamics and climatic variables over space and time for the region of interest. Such maps have been produced for both the Asia-Australia region (Figure 4.1.1) and North America (Figure 4.1.2). Analysis of the correlations between changes in vegetation and climate illustrates regions that are the most significantly impacted, and the environmental factors that are contributing most to this change. This analysis indicates regions and ecosystems of most concern. Understanding how changes in climate have impacted vegetation up to this point will enable better long-term management of forests.

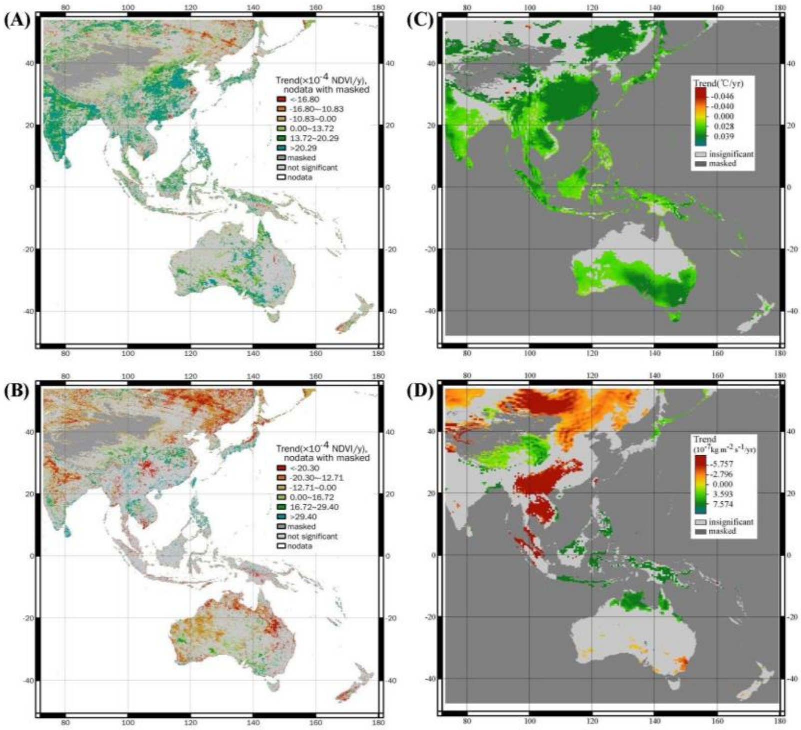

Figure 4.1.1 Spatial distribution of changes in vegetation growth dynamics, air temperature and precipitation in the Asia-Australia (AA) region from 1982 to 2011. (A) Annual productivity (annual mean NDVI); (B) growth seasonality (annual standard deviation of NDVI); (C) annual mean air temperature; and (D) annual total precipitation.

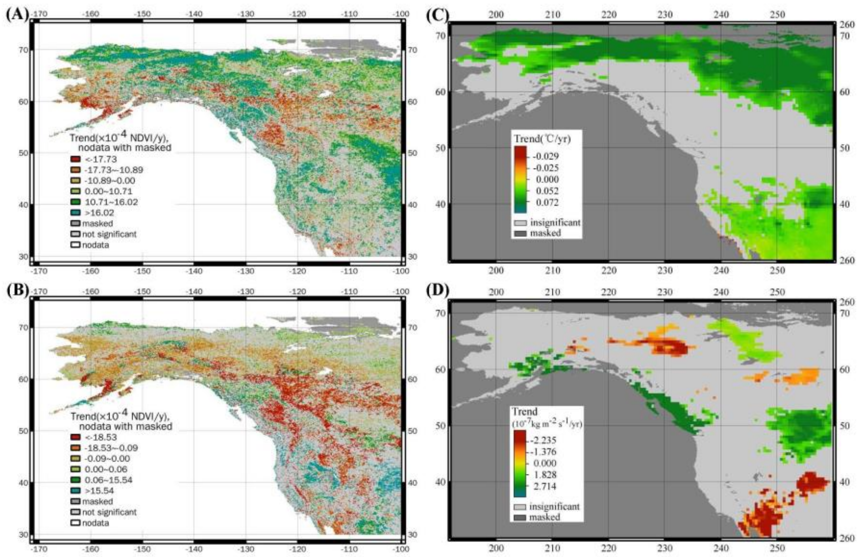

Figure 4.1.2. Spatial distribution of changes in vegetation growth dynamics, air temperature and precipitation in the North America (NA) region from 1982 to 2011. (A) Annual productivity (annual mean NDVI); (B) growth seasonality (annual standard deviation of NDVI); (C) annual mean air temperature; and (D) annual total precipitation.

The mechanisms behind the temporal and spatial dynamics of vegetation productivity in the context of accelerated global environmental change are not well understood. The results of this project indicate that vegetation productivity and seasonality in the Asia-Pacific region vary among different subregions and ecosystems. Additionally, the spatial patterns observed indicate complexity in vegetation growth dynamics, as well as a nonlinear response of vegetation to global climatic changes and other drivers. This has provided insight into poorly understood yet incredibly important relationships, which can now be further explored using the foundation of knowledge provided by this project.

Significance of Remote Sensing

Understanding how vegetation dynamics respond to climate change is critically important for projecting future ecosystem changes. Utilizing NDVI for such extensive studies of the Asia-Pacific region has greatly increased the knowledge of these relationships. This is helpful for supporting the development of policy related to climate change, and for forest managers to develop long-term strategies for maintaining economically viable and sustainable forest ecosystems.

Output 3: Development of niche-based and process-based ecological models.

Niche-based Ecological Models

Niched-based ecological models were developed to predict the impacts of climate change on tree species distributions. The species of interest in this study included: Chinese fir (*Cunninghamia lanceolata),* Chinese pine (*Pinus tabuliformis)*, Masson pine (*Pinus massoniana*), Douglas fir (*Pseudotsuga menziesii*) and Blue Gum (*Eucalyptus globulus*). Chinese fir and Masson pine are the two most socially and economically important subtropical coniferous species in China, while Chinese pine is the most widely distributed conifer in North China. Douglas fir is one of the world's best timber producers and yields more timber than any other tree in North America. Additionally, Blue Gum is one of the most widely cultivated trees native to Australia. Although these five species were the focus for this phase of the project, our modelling technique can be applied to any tree species in any other location. Overall, the objective of developing ecological models was met and exceeded regarding the number of species modelled, and for the Global Circulation Models used.

The climate and vegetation data collected were used to generate maps illustrating the current distribution, and the projected distribution for each species for three time periods (2020s, 2050s and 2080s) based on the most up-to-date climate change scenarios from the IPCC AR5 GCMs. This provides clear visuals of the projected changes in species distribution, as seen by the maps for the current distribution and projected future distribution of Chinese fir (Figure 4.1.3).

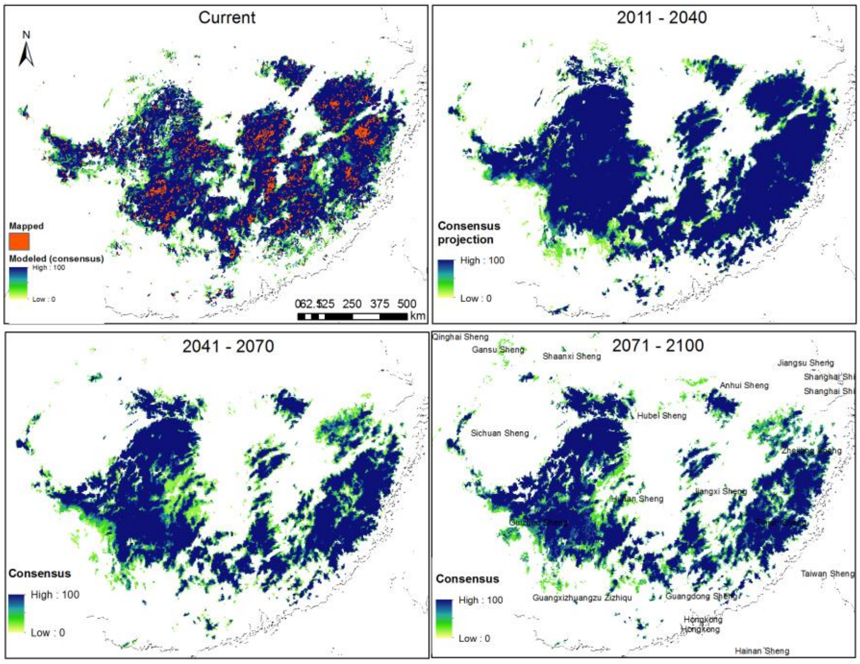

Figure 4.1.3 Maps of consensus projections for Chinese fir distribution for the current conditions and three future periods (2011-2040; 2041-2070; 2071-2100) using 12 climate change scenarios from IPCC AR5 GMCs.

Modeling the climatic niches of forest tree species and projecting their shift in future periods provides a scientific basis for the assessment of climate change impacts on these species. These are considered important essential steps in developing adaptive forest resource management strategies under a changing climate. The maps produced include the area a given species currently occupies and that which is unoccupied but climatically suitable. Additionally, it projects regions that will no longer be hospitable, and regions where there is potential for range expansion. This will allow forest managers to match forest tree species to their suitable climate niches, benefiting the development of plantations, afforestation, and forest ecosystem restoration. This benefit can be expanded to species and locations other than those examined during this project, through the application of this model in the next phase of the project and by other researchers.

Insect Epidemics

The research team also analyzed the relationship between climate and insect epidemics. These included relationships between health levels of individual trees and their vulnerability to insect attack, and the relationship of these to climate variables. However, the relationships were weak in general based on the data available, and no research was published on this topic.

Significance of niche-based models

Due to the slow migration of long-lived tree species, climate change will likely results in a mismatch between the climates that trees are adapted to and the climates that trees will experience in the future. Until now, there has been a lack of studies related to this in the Asia-Pacific. Several tree species, such as the ones studied in this project, are key to social and economic stability in the region, and are important contributors to ecosystem services. Thus, understanding the viability of these species in the areas they currently occupy is essential to maintain healthy, productive ecosystems, which will continue to supply socio-economic benefits and ecosystem services.

<u>Process-based Ecological Models</u>

<u>3-PG</u>

The process-based, stand-level growth model, **P**hysiological **P**rinciples to **P**redict **G**rowth (3-PG) was introduced to explore biophysical and bio-physiological interactions influencing the stand dynamics of a given species to assess the impact of climate change on habitat loss. It was used complementarily with the niche-based models to gain a more comprehensive understanding of the potential shifts in species' distributions. 3-PG is not limited in its application to the tree species examined in this project, which include Chinese fir and Douglas fir, and may be implemented for other species in other Asia-Pacific locations in the next phase.

For this study, the 3-PG model was applied to Chinese fir in the regions of southern China using IPCC AR4 GCMs. As seen in Figure 4.1.4(b) and 4.1.4(c), modelled distributions under climate scenarios A1B and A2 suggest a northward shift with central China likely to become more suitable for Chinese fir. This knowledge will benefit forest managers, particularly those managing plantations. It will allow them to match species to be planted to the regions expected to be within their distribution. This type of planning will allow for long-term sustainability of the forest ecosystems and continued economic benefits from the industry.

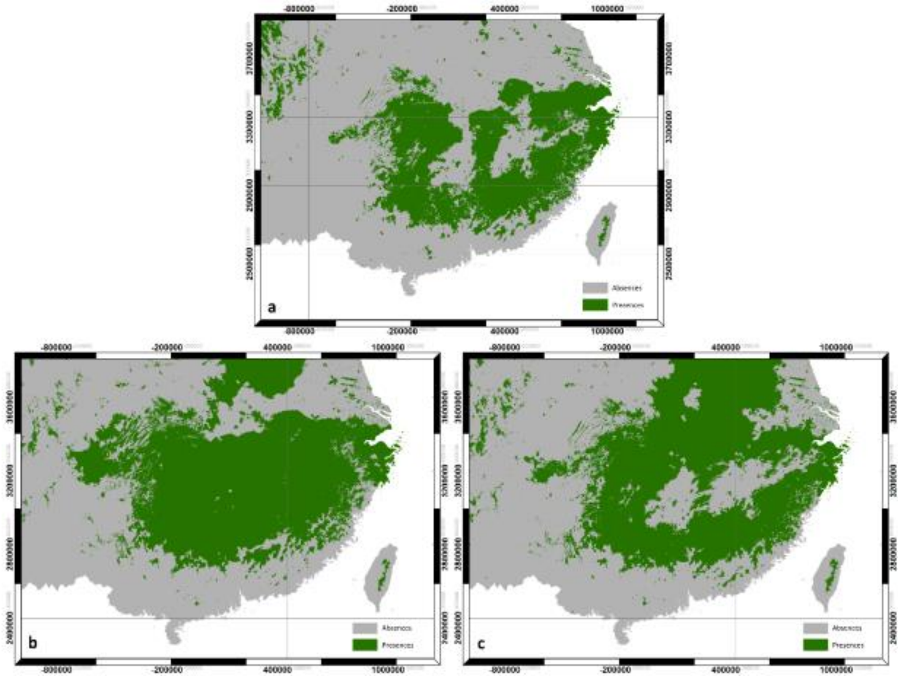

Figure 4.1.4: Graphic representations of modeled Chinese fir distribution under difference climate scenarios. (a) current; (b) A1B; (c) A2

Net Primary Productivity (NPP) was also calculated for Chinese fir, and the spatiotemporal change in productivity was determined. Again, this will benefit forest resource managers, as they can select locations for plantations and resource extraction based on the productivity of the region, to ensure the industry remains economically viable.

The primary objective was to assess the impact of climate change on Chinese fir, specifically on the stand productivity and species distribution. The application of 3-PG was successful in accomplishing this. Additionally, the process-based model was used to confirm or compare with the niche-based model output. Although some discrepancies were observed between the two, these are common occurrences and were deemed minor. Thus both models are considered useful means of projecting future tree species distributions.

Significance of 3-PG

The casual-effects relationship derived from the 3-PG model can be used to enhance our understanding of the reasons for habitat loss. Even more in-depth knowledge of the potential shift in species distribution can be achieved when coupled with the niche-based models. Understanding and quantifying the potential climate change impacts on tree species will aid forest managers at the local scale in developing management strategies that are best suited to the future climates, especially those managers working with plantation species. At the provincial or national level, distribution patterns and forest productivity will assist policy makers in generating more accurate and scientific-based policies.

Fire Management Under a Changing Climate

Fire management under a changing climate was examined from several different facets. Work was done to determine suitable models that can reflect the relationship between forest fire occurrence and burned areas with climate factors in the Chinese boreal forest. The researchers were successful in determining the most suitable model for these analyzes. This will improve scientific research in these topic, which benefits forest managers, as well as citizens and industry in fire-prone areas. The key climate factors that can drive forest fires and impact burnt areas were also determined, which is essential in understanding how fire risk may change over space and time as the climate changes.

An analysis of spatial and temporal patterns of historical forest fire in the Chinese boreal forest was successfully completed, and the causes of the patterns were analyzed. This included an analysis of socio-economic and meteorological factors influencing forest fires. The declining trend in human-caused fires is credited to the implementation of the Forest Fire Prevention Act, which highlights the positive effect of forest fire management policies on reducing fire occurrences. Future management policies in this region, and any region in which these models are applied, will be improved due to a better understanding of the socio-economic influence on forest fires, and the relationship between fire and climate.

Lastly, this project estimated the gases, especially the carbon containing gases, emitted from forest fires in Daxing'an Mountains, China, and their potential influence on the atmosphere. This work is critical in understanding the significance of forest fires in calculating carbon balance and forecasting climate change. The data provided here can be used to calculate a forest carbon balance, model global climate change, and contribute to fire ecology and forest fire management.

The objectives surrounding the analysis of fire risk and assessment were successfully completed for this phase of the project, and work will continue into the next phase. This will include, but is not limited to, predictions of future fire risk, and changes of spatial pattern of forest fire occurrence and burnt areas in the Chinese boreal forest and the southeastern Broad-leaved evergreen forests of China under future climate change.

Significance of Fire Management

Overall, these analyses provide guidance for local forest fire management, and will enable more accurate modelling of fire occurrence, and its impacts of future climate change. Although fire management in the Chinese boreal forest was the focus during this phase of the project, the methodology developed has substantial potential for use on species in other locations of the Asia-Pacific region. This will allow for more comprehensive understanding of the effects of forest fire on advancing climate change and ways to reduce these risks.

LiDAR

LiDAR technology was used to conduct research in Yushan forests a subtropical research site in southeast China. The research examined the relationship between forest biomass (i.e. above-ground and total biomass) and its components (i.e. foliage, branch, trunk and root biomass) with LiDAR derived metrics in three subtropical forest types – coniferous, broadleaved, and mixed forests. The strength of the relationships were evaluated within each forest type to determine the accuracy of the various LiDAR metrics in estimating the biomass and biomass components among different forest types. This will improve the quality of research performed using LiDAR, as well as any subsequent management plans or policies that result. The methods and results from this project's research may provide useful information for understanding regional carbon cycling, and developing forest management strategies related to carbon balance, timber production, and fire hazards in China and other subtropical countries.

LiDAR was also used in tandem with the aforementioned 3-PG model to assess regional stand volume of Douglas fir at the MKRF in British Columbia, Canada. The objective was to predict Douglas fir growth on a site-by-site basis, which was achieved by applying both LiDAR and 3-PG. Predictions of standing volume from LiDAR, 3-PG, and field-based data were then compared and contrasted to assess the relative benefits and drawbacks of each approach.

There are a number of benefits to using both process-based and LiDAR derived estimates of stand volume. The 3-PG estimates provide additional information to forest managers, as the tools most often used by foresters (empirical growth models and site index tables) are not well designed to adapt to growth changes under a changing climate. Process-based growth models provide an effective way to investigate the potential impacts of climate change on the forest estate within a quantitative framework. The LiDAR based predictions of stand volume provide high spatial resolution sampling of forest structure that can complement field-based volume inventories. LiDAR derived inventories can assist in forest management decisions and planning, as well as report on carbon storage and sustainable management practices in managed forests.

Comparisons between these outputs will also be beneficial. Instances where LiDAR predictions of stand volume exceed 3-PG predictions may indicate an incorrect stand age in the database, the application of some silvicultural treatment such as fertilizer or stand level thinning where a growth response has occurred. In contrast, when LIDAR predictions are lower than 3-PG's, this may be indicative of a disturbance, which in the case of MKRF could be Douglas fir beetle or other types of defoliators, root rot, or abiotic disturbances such as snow damage or wind throw.

Significance of LiDAR

Future research that utilizes LiDAR can now be improved through greater understanding of the accuracy its predictions. Coupling LiDAR with 3-PG will provide forest managers with highly accurate information, allowing the best possible management strategies to be developed. This should provide a better understanding of the current state of managed forest ecosystems, and yield better preparation for and knowledge of the potential changes that will result from climate change.

Output 4: Pilot site studies, and development of recommendations for SFM practices for adaptation.

<u>Application and integration of niche-based models</u>

Niche-based modelling was applied to the MKRF to project the shift in climate and climate niches for ecosystems and species at these. This was done using climate change scenarios from the IPCC AR4. These projected changes in bioclimate envelopes for ecosystems will help generate better forest management strategies to maintain healthy and productive forests in the future.

The work for the Fujian pilot site was completed, however inconsistencies in the data delayed the progress on the analysis of this work. As such it was not completed for this phase of the project, but will be revisited in Phase 2 if necessary.

Significance of application and integration

The application of these models to the pilot sites has provided accurate projections of changes in climate and habitat suitability for the species of interest. Better long-term management planning, and more appropriate species selection for plantations and reforestation efforts can be employed based on the observed changes in the suitable climate niche of the species. This is a valuable tool for forest managers and policy developers to generate long-term strategies that will ensure forests continue to provide ecosystem services and socio-economic benefits.

Application of Process-based Models

Tools were developed to bridge niche-based model predictions with one or two process-based models. These models were applied at the various pilot sites – MKRF, Canada; Fujian site, China; Central Highlands Region, Australia. The overall objective of developing adaptation strategies in management planning, and producing decision-matrices to rank various management strategies was achieved through the application of these models at the pilot sites. Additionally, the research team identified the impacts of climate change on forest and forest ecosystems in MKRF, which were summarized as seven indicators.

TACA/LANDIS-II

The TACA and LANDIS-II models were applied to the pilot site in the Central Highlands Region (CHR) in Victoria, Australia. This modelling was conducted for 32 *Eucalyptus* spp., however the focus was on *Eucalyptus regnans*. *E. regnans* is the most sought after species for timber production in the region, and is a key species in water production, carbon stocks, and habitat for native wildlife.

These models were used to project the response of species and ecosystems to climate change. The TACA-GEM and TACA-GAP models were used to model the suitability of a site for species regeneration and survival, and to estimate the annual Net Primary Productivity and maximum biomass that a species can achieve on a given site, respectively, under different climate scenarios. LANDIS-II was used to simulate ecological processes such as succession, seed dispersal, disturbances, and climate change, using the regeneration and productivity parameters from data from TACA-GEM and TACA-GAP, respectively. A meta-model was then employed to assess the impacts of adaptation strategies on mitigating the impacts of climate change on forest services.

These models indicated the spatial impacts of climate change on a tree species with respect to suitable areas for regeneration and productivity, as well as the impact of management, fire, and climate change on the growth stage distribution. The impact of climate change on ecosystem services, such as harvestable timber and amount of habitat for native possum species, were also considered. This information will be useful to forest managers when allocating regions for certain economic or environmental use.

A range of alternative management scenarios were developed and modelled to test the interaction between management, climate change, and ecosystem services. The tradeoffs between ecosystem services were examined for all management scenarios. The researchers were then able to identify the scenario most likely to facilitate adaptation to climate change. Current management strategies fail to reduce the vulnerability of forest types/tree species under future climate change. These results highlight the need to base management strategies on future climate conditions, emphasizing the need for accurate climate models such as those produced by this project.

Resource managers can use the information from this modelling and comparative analysis to determine the strategies best suited for their desired management outcomes. This will help to maintain socio-economic benefits and environmental services in the face of climate change. The methodology for the application of these models can be extrapolated to other locations, focusing on other species. Thus, these techniques represent a great opportunity for researchers and forest managers to develop adaptive strategies for various forest ecosystems.

Significance of TACA/LANDIS-II

This case study for the CHR has identified that forest communities currently dependent on the forest ecosystem services and economic benefits are vulnerable to climate change. This work has identified adaptation strategies to maintain as many services and benefits as possible, which will help guide management and policy decisions for the area.

FORECAST Climate

FORECAST Climate is a process-based model that was applied to the MKRF in coastal British Columbia, and the Fujian pilot study area in China. The principal objective was to assess the long-term impacts of climate change on forest growth rates and mortality, and develop adaptation strategies in forest management practices and species selection.

The application of FORECAST at MKRF focused on the evaluation of the long-term impacts of two alternative climate change scenarios on the growth and development of Douglas fir, Western hemlock, and Western redcedar. In this study, climate change projections were taken from two IPCC AR5 GMCs, with outputs generated for 2020, 2050, and 2080. This model projects the impacts of climate on tree growth, ecosystem development, and mortality rates through their relationships to temperature and water stress. Annual merchantable volume production could then be determined based on the expected growth rate. Additionally, the model projects decomposition rates and nutrient cycling under climate change, to further understand how these environmental factors will influence the productivity of the ecosystem. A database of stand-level growth summaries was then generated for use in the landscape-scale analyses. The calibrated model is available for managers to evaluate additional management options and/or climate change scenarios for any tree species of interest.

FORECAST Climate was also applied to Chinese fir dominated forest plantation in Fujian Province, China. This was done to simulate the stand-level impacts of four alternative climate change scenarios on the growth and development of Chinese fir plantations. Similar to the work done at MKRF, FORECAST Climate projects the impacts of difference climate scenarios on the growth response index and its relations to temperature and water stress, as well as the impacts to productivity through litter decomposition rates. Following this, a landscape-level analysis of the trade-offs between economic fiber production and ecosystem services in the context of climate change was conducted for a series of alternative management scenarios using output from FORECAST Climate. This trade-off analysis utilized a landscape-scale model, Landscape Summary Tool (LST). The LST is a decision-support tool, which managers of plantations can use to evaluate landscape-scale tradeoffs between the economic and ecosystem related variables. It generates a decision matrix spreadsheet giving users the capability to easily score and rank management options through the weighted sum of the indicators for each scenario based on their own determination of the importance of each indicator according to the forest management purpose.

This work was successful in meeting the principal and specific objectives for the application of FORECAST at MKRF and the Fujian pilot sites. The research results from FORECAST Climate demonstrate the value of employing a process-based model with relatively minor calibration requirements to evaluate the potential impacts of climate change on key ecosystem processes and long-term productivity.

Significance of FORECAST Climate

The calibrated model and LST decision support tool developed from the application of FORECAST at the MKRF and the Fujian site, respectively, are available to be used by forest managers. These provide a framework for managers to assess climate change impacts, and develop adaptation strategies in forest management practices and species selection. The LST improves the evaluation of the implications of different plantation management options for a range of indicators using the weighting options provided with the tool. This tradeoff analysis will allow the best possible decisions to be made to achieve forest management targets, and maintain healthy ecosystems under a changing climate. Although this research was focused on Douglas fir and

Chinese fir, FORECAST Climate and the subsequent tradeoff analyses can be done for any tree species in any location, provided the necessary reference climate data and species-specific parameters are available (see the Technical Report for details of the data requirements).

Hydrological Modelling

The eco-hydrological model, DLM-Ecohydro (BEPS-TerrainLab V2.0), was developed from a Dynamic Land Model. It is used to simulate annual mean temperature, evapotranspiration, soil water storage, surface and subsurface runoff, as well as gross and net primary production. The model was applied to the Fujian watershed study area in China, and MKRF in British Columbia to simulate water balance and the carbon cycle for the historical period (1980-2010) and future (2010-2100) using different RCP scenarios.

This model has an easy to use interface, and can be applied to any location by inputting climate and land surface data specific to that site. Forest resource managers can use the projections and maps generated for each output to develop forest adaptation strategies to maintain healthy forest ecosystems despite potential environmental stresses.

Significance of Hydrological Modelling

This model is unique in that it integrates hydrology and ecology, which are most often looked at in isolation. This coupling generates a more accurate representation of movement of water through the physical environment and biological systems to generate a better understanding of the earth surface processes. This type of integrative analysis is crucial to developing an accurate understanding of the implications of climate change, as forest ecosystems are greater than the sum of their parts. The DLM-Ecohydro model is thus a major advance in hydrological modelling, and as a tool for developing forest management strategies to adapt and mitigate against climate change.

Modelling Ecosystem Carbon Dynamics

An analysis of ecosystem carbon under various climate change scenarios was done for the Pitt River Watershed, which encompasses the MKRF pilot site in British Columbia, Canada. Several carbon indicators were modeled including carbon storage capacity, carbon pools size, carbon fluxes, and the capability of carbon exchange with the atmosphere.

Forest managers can use this type of information in tradeoff analyses of management practices to determine the best approach for maintaining relatively stable carbon stock in the regions current carbon pools. This will allow different management regimes to be compared and contrasted regarding their impact on carbon pools in the context of achieving sustainable timber harvesting. This research also projected carbon fluxes for the Pitt River watershed to determine if the region will become a carbon source or sink in the future. This highlights potential risks of the forest becoming a source of carbon, and enables forest managers and policy makers can take proactive measures to return it to a carbon sink.

Significance of Modelling Ecosystem Carbon Dynamics

The ability to compare the impacts of various management strategies on carbon pools and fluxes will enable the development of strategies that are best suited for the region of interest and the specific management objectives. Knowledge of the future changes to the ecosystems carbon fluxes will be vital for achieving sustainable forest management objectives. This will allow the necessary steps to be taken to transition forests expected to be carbon sources to ones that are carbon sinks so as to help mitigate climate change.

Model Integration for Decision Making

Several models were integrated in a framework that assembled existing science, technology, and essential tools to help managers and decision makers make sound decisions regarding sustainable forest management under the changing climate. This framework was applied to the MKRF pilot site in British Columbia, Canada. Seven climate related indicators were selected as major indicators that might have the greatest response to climate change. These were developed so that SFM could be evaluated under climate change. A multi-value trade-off analysis framework for strategic decision and planning was then employed to explore and understand the tradeoffs for multiple management related values. This framework is able to assess the impacts of different forest management regimes on ecosystem values, evaluate the influence of alternative management strategies on these values and their tradeoffs, as well as address some of the complex effects of climate change on the ecosystem and decision making process. The last component of this integration was to present information in a simple way through the use of risk classes. This methods of clearly sharing information will assist managers and general stakeholders in understanding the complex forest management issues, how to deal with these issues, and the risks they face when dealing with them. Although this framework was applied in Canada, these tools can be used in other Asia-Pacific locations to solve local management issues in a cost-effective manner.

The development of this type of analysis is critically important, as managers and planners need to understand the potential tradeoffs associated with a broad suite of goals that sustainable forest management attempts to achieve. The work done here encompasses broad objectives, such as conserving biodiversity, combating climate change, carbon storage capacity of forests, and respecting aboriginal culture and rights, as well as more standard objectives such as timber volume and revenue. This trade-off analysis can be conducted for alternative management strategies and indicates the relative importance of each in achieving the defined management goals.

Together with the risk assessment that is conducted in relation to the trade-off of management objectives, this framework will strengthen the decision making process for forest managers.

This model integration framework provides a tool for forest managers to determine the best management strategies to achieve SFM objectives in the context of climate change. The trade-off analysis is complex enough to be used by those who are very skilled in this type of analysis and have access to detailed information, but is also simple enough to be used by those with less experience and less complex information. This framework provides managers and decision makers straightforward methods to quantify the individual or combined benefits and tradeoffs of multiple, potentially conflicting objectives.

Significance of Model Integration for Decision Making

The framework developed for MKRF provides a platform to address the inherent complexity of resource management objectives, taking into consideration ecological, biophysical, environmental, and social components, and accounting for the various concerns and objectives of stakeholders. The use of indicators and values to represent management objectives allow this method to be adaptive to evolving goals, while providing support for multiple objectives management, participatory planning, and managing risks and uncertainty associated with climate change. The multi-value trade-off framework has great potential for application in forest management and land-use planning.

Output 5: Communication, network building, and technology transfer.

<u>Network Building</u>

The project formed a valuable research team and advisory committee. The advisory committee members consisted of climate and forest research experts in the Asia-Pacific region from Canada, China, the US, Australia, Malaysia, and Indonesia. The research team members were from universities, government agencies, and research institutes.

The network was built gradually through various activities including events held at The University of British Columbia (UBC), Canada (Climate Change Adaptation - Sustainable Forestry Management Workshop) and in Yichun, Heilongjiang Province, China (International Conference on Response of Forests and Adaptation Management to Climate Change), which were designed for the project, and invited experts from over the world to discuss the nature of the project and knowledge gaps that may exist. In the initial stages, the project management team members visited pilot sites and also formed the local communication network. The expert network and communication with local and forest communities were further expanded and enhanced throughout the progression of the project.

UBC hosted six visiting scholars from multiple universities in China. Their length of stay varied between 6 to over 17 months. They worked with members of the research team at UBC, and audited several courses covering such topics as Forestry in British Columbia, Forest Stand Dynamics, International Forestry, Technical Communication Skills, and Scientific Writing. This exchange opportunity strengthened the relationship between team members and increased collaboration on research, bringing together knowledge from different backgrounds and forestry practices to yield the best possible results.

Significance of Network Building

The network of scientists, stakeholders, and policy makers from across the Asia-Pacific region allowed this project to achieve APFNet's goals of capacity building and information exchange. The international collaboration strengthened the project team and benefited the researchers, institutions, and countries involved, through an immense transfer of knowledge and skills regarding tools, technology and management planning.

Workshops

A training workshop was held in Kunming, China from July 1, though July 11, 2013. A training handbook was assembled for participants, which included an overview of the issues and challenges for forestry in the Asia-Pacific region, touching on statistics and trends of forestry activities, management and policy information, the challenges resulting from climate change, and forest management strategies for climate change adaptation and mitigation.

Tools to aid in sustainable forest management were a focus of this workshop. Participants were guided through a framework to develop and apply the most useful and appropriate models to achieve the desired knowledge outcomes when being applied under various conditions. The development, application, and relevance of several tools and models developed and utilized in this project were presented at the workshop. This included: conventional growth and yield models; ClimateAP; carbon budget models; LANDIS-II model; climate niche models for ecosystems and species; FORECAST Climate; TACA-GEM model for species regeneration. The workshop also involved hands on fieldwork related to collecting and assessing data sources to implement models, giving participants a chance to improve their skills using these tools. Forest management strategies for adaptation and the potential impacts of climate change were also discussed in the context of the tools and data they were using.

Significance of the Workshop

This workshop allowed the outputs and technological advances made by this project to become available to some of the research community in the Asia-Pacific. Additionally, the report *Sustainable Forest Management in a Changing Climate* was produced as a compilation of 10 reports from participants of the workshop on topics relating to management and climate change adaptation of forests in their country. The booklet is publicly available.

Seminars

Research seminars were conducted at several universities and research institutions to audiences ranging from 50 to 120 people. These events were aimed not just at academic audiences, but also presented to government bodies as a way of connecting them with the research and tools produced by the project, so that they may be aware of the importance and urgency of climate change adaptation and of the tools available for them to act. These events contributed significantly to the project's successful networking, and were an essential means of expanding the scope of the network beyond academic researchers to include government agencies and industry.

The research seminars were half-day presentations held in conjunction with other local research presentations. The presentations were targeted towards the local region, with the topics and tools discussed being relevant to the adaptation of the local ecosystems. These events informed people throughout the Asia-Pacific of the project's findings, the tools that were available and how to use them, and the impacts that climate change will have of forests in the Asia-Pacific. Presenters touched on how climate change will impact forestry, including job security, forest productivity, fire risk, ecosystem services and resilience, and carbon storage. The research being done to address these issues was then presented as it related to the local community. This included introducing people to ecological models, ClimateAP, pilot site research, and the tradeoff analysis of management strategies.

Team members participated in 16 seminars over the duration of the project, which benefited approximately 860 participants (Table 2.1). The location of these seminars is as follows: in Malaysia: Universiti Putra Malaysia; in India: Indian Forestry Services; in Taiwan: National Taiwan University, National Taiwan Normal University, Taiwan Zhongxing University, Jiayi University, Ilan Univeristy, and the Taiwan Forestry Bureau; in Mainland China: Northwest Agriculture and Forestry University of China, Nanjing Forestry University, Fujian Agriculture and Forestry University, Hebei Agriculture University, Xiamen University, and the Chinese Academy of Forestry; in Australia: University of Melbourne; in Canada: University of British Columbia.

Significance of Seminars

These seminars improved the project's network and communication with government agencies, industry, and universities throughout the Asia-Pacific. These events were fundamental in disseminating knowledge about the importance of climate change on Asia-Pacific forest ecosystems, and showing people the tools and information that are available to them to increase their adaptive capacity by improving research, forest management, and government policy. The regional collaboration that ensued benefited the remainder of the project's outcomes, and will continue to provide benefits into the next phase.

International Union of Forest Research Organizations World Congress

Team members from this project co-organized a policy-training program carried out at the International Union of Forest Research Organizations (IUFRO) World Congress held October 5-11, 2014 in Salt Lake City, USA. A poster summarizing the accomplishments of the project was presented. Additionally, three project team members made presentations focusing on: ClimateAP and its use in projecting the climate niche and productivity of forest trees in future climates in the Asia-Pacific; Climate change impacts in the temperate forests of Southeast Australia: can forest management reduce vulnerabilities?; A multiple values trade-offs framework for climate change adaptation.

Significance of IUFRO

The presentations made by members of the research team at IUFRO were well received. This event was an excellent opportunity to make the international forestry community aware of this projects achievements, and receive feedback which will be beneficial for the work done during the second phase. Attending the IUFRO World Congress broadened the network of this project, facilitated information exchange in both directions, and promoted sustainable forest management to help mitigate and adapt forests to climate chance, which are in line with the overall objectives of APFNet.

Experts' Opinion Questionnaire

A questionnaire was developed and distributed to experts in the field of climate change and forestry from countries throughout the Asia-Pacific region. The main objectives of the questionnaire were to identify experts' perspectives and knowledge on the impacts of climate change and forest adaptation in the Asia-Pacific region, to explore the implications/recommendations for adapting forests to climate change in the Asia-Pacific region, and the challenges this with pose. The questionnaire was successful in achieving these objectives due to well-developed questions, a strong response from an array of countries and professional positions, and appropriate methods of analysis to rank responses and identify trends. The information gathered was also intended to provide support for further research in developing climate and ecological models, developing adaptive tools and strategies, and establishing a cooperative network of information sharing for sustainable forest management and rehabilitation in the Asia-Pacific region. This study has increased the understanding of the consensus and discrepancies about climate change among experts, the current state of knowledge surrounding this issue, and provided guidelines for further research for this and future projects.

There was consensus that climate change consequences of high concern include forest disturbances and economic impacts to the forestry sector. There was also agreement that localized climate change related actions for adapting forestry to climate change are lacking, and those initiatives that have been undertaken have yielded unsatisfying results. Participants indicated public awareness, legislation and lack of scientific guidance as the major challenges to climate change adaptation. Exacerbating these challenge is the low accessibility and suitability of existing forest adaptation technologies, and a lack of local predicted climate change scenarios and forest adaptation strategies and policies specific to the region. Experts generally agree that addressing the lack of legislation and policies, increasing scientific support and management guidance are needed to address climate change.

There was however differences between regions and professions regarding the negative and positive impacts, and challenges for adapting forestry to climate change. This reinforces the notion that the impacts of climate change and the methods needs to mitigate and adapt to it will vary across the Asia-Pacific due to the region's heterogeneity with regards to ecosystems, governance, and susceptibility to climate change.

Significance of Questionnaire

Overall, this survey has highlighted the importance of the outputs from this project. The research team has been able to address several key concerns raised in this questionnaire, notably increasing scientific support for local predicted climate change scenarios, forest adaptation strategies, and ecosystem dynamics through the models and tools developed. Ecological models for predicting shifts in species' suitable climate niches, and FORECAST Climate provide guidance for forest managers and policy makers to develop better forest adaptations strategies. Pilot site experiments have enabled the development of adaptive strategies for climate change through the integration of model prediction with local forest management practices. As well, the lack of publicly accessible and high-resolution climate models has been addressed through the development of ClimateAP. The development of web tools facilitates easy access to climate and ecological models, and other information pertinent to locations throughout the Asia-Pacific.

Overall, the objective of network building and technology transfer was achieved through the combined outcomes of the establishment of the network of scientists, stakeholders and policy makers; the workshops conducted; the attendance to international conferences; and surveying experts on issues of forestry and climate change.

Output 6: Development of web-based climate tools for APFNet.

Several measures were taken to develop web-based tools that would make the information and tools produced by this project easily accessible to researchers, forest managers, policy makers, and stakeholders from around the world. This included the development of a project website (http://asiapacific.forestry.ubc.ca) that serves as a gateway to the project and includes research objectives, organization, research team members, events, etc.

Additionally, a map-based version of Climate-AP was made available through the web browser http://climateap.net/ to provide interactive access to scale-free climate data for historical years and future periods. It also allows spatial visualization of climate maps. As well, spatial projections of climate niches generated from outputs of ecological models are available for Chinese fir, Chinese pine, and Masson pine for three future periods. This is a freely available, easy to use, interactive visual, which displays climate predictions and bioclimate envelope maps for the given tree species in a straightforward manner. This will allow scientists, stakeholders, policy makers, and curious citizens easy access to the most up-to-date information and knowledge on climate change for anywhere in the Asia-Pacific region.

Significance of web-based ClimateAP

These web-based tools will allow easy access to the latest knowledge and research generated by this project, and provides the capacity for those with little modelling experience to be able to access high-resolution climate data. Together, these will facilitate and improve the quality of future research on climate change in the Asia-Pacific region. This feely available information and climate/niche modelling tool will help to develop more targeted and effective management strategies to mitigate and adapt to climate change, which will help maintain healthy forest ecosystems that continue to supply socio-economic and environmental benefits to the people of the region.

4.2 Project Impacts

The Adaptation of Asia-Pacific Forests to Climate Change project has advanced the technology and knowledge required to mitigate and adapt forests to climate change. This is necessary to ensure healthy and productive forest ecosystems, and social, economic, and environmental sustainability throughout the Asia-Pacific region. The initial literature review and results from the survey of experts emphasized the necessity of this project to address mitigation and adaptation of forest ecosystems. This project identified where science, technology, and policy were lacking with respect to adapting forests to climate change, and subsequently produced outputs to improve the capacity of these sectors. The research team has provided extensive scientific knowledge of tree species, ecosystems, and current and future climate in the Asia-Pacific region, as well as freely available cutting edge tools and technology to understand the processes of ecosystems and their interactions with the changing climate.

This project addressed the lack of models and tools specific to the Asia-Pacific region. These are required to generate accurate predictions of climate change impacts on the region's forest ecosystems, which are needed to develop successful forest management strategies and policies. Ecological models provide the ability to predict shifts in suitable climate conditions for tree species distribution, while pilot site research involving process- and niche-based models enable the development of adaptive strategies for climate change through the integration of model prediction with local forest management practices. These tools will improve the development of adaptive forest resource management strategies under a changing climate, and species selection for plantations, and afforestation and reforestation efforts. Understanding the impacts of climate change on tree species of economic importance is crucial to ensuring continued socio-economic benefits, ecosystem services, as well as the social and cultural integrity of forest ecosystems.

Tools such as ClimateAP and FORECAST Climate represent a large step forward for climate modelling. The potential use of these models is high due to their ability to be applied to species and locations throughout the Asia-Pacific. They will influence the design of future experiments and analysis of climate data, and will promote increased study of climate change in the Asia-Pacific region. The tradeoff analyses associated with FORECAST Climate provide a decision-support tool to forest managers to develop strategies that consider both the environmental and economic costs, which will help them achieve their management targets. Overall, these models will lead to environmental, economic, and social benefits, through improved forestry policies, and adaptive management strategies.

The ClimateAP web-tool addressed the lack of publicly accessible and high-resolution climate models. This tool facilitates easy access to climate and ecological models for any location in the Asia-Pacific, and encourages the study of climate change in the region. The high accuracy and quality of the data produced by ClimateAP will allow forest managers, resource planners, and policy developers to generate more targeted and adaptive management strategies, and more successful long-term forestry policy. This will ensure continued social, economic, and environmental benefits into the future, through the maintenance of forestry dependent industry, jobs, and communities, and continued gains from the ecosystem and cultural services provided by forest ecosystems.

Understanding and quantifying the potential climate change impacts on tree species with models such as 3-PG and FORECAST Climate will aid forest managers at the local scale in developing management strategies that are best suited to the projected future climates. Projections of changes in tree species niche distributions can improve large scale landscape planning, especially with regards to afforestation and ecosystem restoration. At the provincial or national level, projected species distribution patterns and forest productivity will assist policy makers in generating more accurate and scientific-based policies, and resource management strategies. This will in turn yield socio-economic and environmental benefits, as several tree species, such as the ones studied in this project, are key to social and economic stability in the region, and are important contributors to ecosystem services.

The workshops, training programs, seminars, and network building allowed the project's outputs and technological advancements to be made available to a wide audience involved in a variety of fields including research, forest management, and policy development. Introducing people to the tools developed during the project has facilitated further research in this field and improved the efficiency in which progress can be made by teaching people how to use these tools almost immediately after they were developed. Targeting seminar and workshop topics to participants' local regions made them that much more impactful, as people were better able to understand the impacts of climate change as they the pertained to their country and its ecosystems. Building on this, forest managers, government officials, and researchers, are then well equipped to make decisions and use tools that are the most appropriate for their unique situation. These components of network building have improved regionally specific knowledge of climate change impacts on forests to people in a broad range of professions, which should improve future research and adaptive capacity throughout the Asia-Pacific.

This project has made vast contributions to the academic world, as well as management and policy development via its publications, books, technical reports, policy and management guidelines, and follow up research. The projects' published work includes 3 reports, 20 research papers, and 2 books, which have significantly contributed to the advancement of science and technology surrounding climate change and forestry in the Asia-Pacific. These publications and activities will improve the development of Sustainable Forest Management strategies, improve management decision-making, and allow more informed policy to be developed. Several follow up activities are planned as part of Phase II of this project, which has already been approved by APFNet. The next phase will improve upon research conducted in Phase I, and will expand to include more pilot sites throughout the Asia-Pacific region. The work produced by this project and the subsequent work in the next phase will lead to improved research and strategy development regarding climate change mitigation and adaptation, which will allow continued environmental, social, and economic prosperity throughout the region.

Overall, this project has improved the understanding of the impacts of climate change on forest ecosystems. It has provided the scientific knowledge and tools to implement more sustainable forest management, and to develop the best possible adaptation and mitigation strategies. This will not only address climate change and its related issues, but will enhance biodiversity, reduce carbon emissions, improve forest ecosystems, and improve the ability of forests to provide social and economic benefits to forest-dependent communities throughout the Asia-Pacific region.

4.3 Sustainability

The benefits of the project will continue well after this project, and even its next phase, have been completed, through the projects website, publications, and the online version of ClimateAP. Additionally, there will be continual opportunities for those involved in the project to deliver training to stakeholders, policy makers, and forest mangers regarding the tools developed from the project. The workbook that was developed for the Kunming training workshop is also publicly available, and contains detailed information regarding the development, application and relevance of models and tools related to sustainable forest management.

As well, a second phase of the project has been proposed and approved by APFNet. It will run from January 1st, 2015 to December 31st, 2017, focusing on China and Southeast Asia. This project will expand and improve upon the research and tools developed from the first phase, and be applied to a broader range of ecosystems and associated communities. More pilot sites will be utilized in the coming phase, which will increase the availability of the tools and models in the Asia-Pacific. This will provide these areas with detailed technical support for conducting climate and ecological modeling, and evaluating various management strategies. In addition, this project will focus on making information and technology available for use by local practitioners through training, web tools, and technology transfer.

5. CONCLUSION, LESSONS LEARNED AND RECOMMENDATIONS

5.1 Conclusion

This project was successful in meeting all of its outputs and objectives in the time allotted, while staying under budget and even increasing the initially defined scope. The research team has provided a detailed review of the fundamental science of climate change as it relates to forest ecosystems and forest-dependent communities in the Asia-Pacific, and also reviewed the availability of policy to enable the region's inhabitants and forest managers to adapt and mitigate climate change. High-resolution climate models were developed, which will facilitate and improve the accuracy of future climate research in the region. The ecological models developed will allow more accurate predictions of the impacts of climate change on economically important species. These models incorporated with management trade-off analyses will contribute to the successful development of sustainable forest management strategies, and ensure forests contribute to mitigating climate change. Network building and technology transfer were successfully achieved through the experts' opinion questionnaire, the participation of team members in international conferences and training workshops, and through UBC hosting several visiting scholars from China. The development of the web-based version of ClimateAP met the final objective of developing web-based scientific tools, which will enable a much wider audience to carrying out climate change and forestry-related research for the region.

The research, models, and tools that have resulted from this project are crucial for increasing the understanding of the impacts of climate change on Asia-Pacific forests, and developing successful strategies to ensure they remain environmentally and economically viable, and continue to provide social and ecosystem services. Our project team has done an excellent work on achieving and exceeding our objectives, and may have significantly contributed to the science and application in forestry adaptation to climate change in the region.

5.2 Lessons learned and recommendations

The management and research team learned several lessons throughout the duration of this project. One such lesson is that although climate change is very apparent from the Asia-Pacific regional scale, the impacts and effects are very diverse when examined more locally throughout the region. As such, one key observation is that one model, whether it be climate or ecological, does not fit for every location. Models need to be tailored to specific issues, relationships, and species for the location of interest to ensure that they are accurate and useful. The use of the three pilot sites highlighted these differences, as the management objectives and model application differed between the locations, and needed to be adapted to the local situation.

Another key lesson is the importance of government action in adapting and mitigating forests for climate change. Those at the forestry management level can only do so much. As such, government planning, policy, implantation of strategies, monitoring, and financial support are necessary to achieve sustainable forest management objectives, and ensure best practices are carried out to sustain forests and mitigate climate change.

The management team observed that there are few tools available to support government decision-making. This hinders successful government action, previously stated to be of great importance for managing forests in the face of climate change. As such, the models and research produced by this project aimed to fill this gap, and improve government decision-making capacity.

As well, the project team learned the importance of public education and participation, particularly by stakeholders, and those involved in decision-making. Their involvement would allow the developed research and management objectives to be shared, and for the public opinion to be heard and incorporated into the project where appropriate. This type of participation was not done for this phase, however it will be incorporated in Phase II.

This phase of the project successfully solved technical problem related to climate and ecological models, evaluated management and economic trade-offs, and made modeling resources publicly available, among many other achievements. However, the importance of scaling this work up has been noted. Although management aspects were investigated through the application of models at the three pilot sites, this work was found to be limited in space and time. The application range of these outputs is minor compared to the scale of the Asia-Pacific region as a whole. This limits projections and information that can be made available related to adaptation of management strategies. Additionally, there will need to be further investigation into the long-term impacts of management strategies, as the research thus far has been limited in the timescales examined.

Experience indicated that the value of the project advisory teams was limited. The Project Steering Committee played little role in the evolution of the project, probably because they had little 'ownership' in the project. The large number of partners from multiple institutions also reduced the potential effectiveness of the Steering Committee, and the APFNet Management should consider whether such Steering Committees are really useful and effective in all cases. Instead of requiring that one be set up for all projects, it might be more effective to require such Committees for certain projects only.

Another issue that APFNet needs to recognize concerns data availability. In some cases, data are not available because they have never been collected. In other cases, data have been collected, but are not openly available to the scientific community. This is inconsistent with the aims of APFNet, but may be the result of government policies or other restraints. There is little that the APFNet can do about this, other than to keep demonstrating the benefits of open access to data and results.

Annexes

A. Project Implementation status
B. Financial statement(including balance sheet, source and use of Funds statement, and expenditure details) by both category and activity
C. Project audit report
D. Project outputs, such as technical reports, key project documents (workshops, field visits, technical visits, trainings etc.), publications, brochures, webpages, etc.
E. 2-3 Feature stories from the project for promotion
F. Photos, media clips and other materials used/available for project outreach

Annex A Implementation status (scheduled versus actual)

Project Objective/Outputs/ Activities (in line with PD/AWPs)	**Indicators** (in line with PD/AWPs)	**Baseline of activities**	**Progress made (%completion of activities and degree of output/objective achievement)**	**Appraisal time**	**Actual time**
Output 1	Literature reviews and gap analysis		100%		
Output 2	ClimateAP with five GCMs from IPCC AR4		ClimateAP with 15 GCMs from IPCC ARR, >100%		
Output 3	Niche-based models for three tree species and projections with five AR4 GCMs		Niche-based models for five tree species and projections with six AR5 GCMs, >100%		
Output 4	Process-based models, indicators and recommendations		With addition of carbon budget, >100%		

Output 5	Workshops, conferences, extension notes and network and capacity building		With addition of surveys, >100%		
Output 6	Web based tools		100% achieved.		
Additional activities	Remote sensing, forest fires and Lidar		>100%		

Annex B(1) Details of project cost by category

Expenses (USD)	APFNet Grant					Counterpart Fund			
	Anticipated A_1	Actual B_1	Accrued	Variance $C_1(A_1-B_1)$	Variance rate $D_1(C_1/A_1*100\%)$	Anticipated A_2	Actual B_2	Variance $C_2(A_2-B_2)$	Variance rate $D_2(C_2/A_2*100\%)$
Inception Funds	22,500	21,386	0	1,114	0.05	22,500	22,500	0	0
International and national consultants									
Research and Modeling (Climate models/ niche-based models/ forest management models/ watershed models/ integration tools)	381,000	280,712	87,738	12,550	0.03	269,500	269,500	0	0
Study tour & travel expenses (Conferences/ research site visits/ field surveys)	140,000	130,212		9,788	0.07	85,000	85,000	0	0
Survey / Case Study (Fujian/ Nanjing/ Australia/ British Columbia)	300,200	210,573	43,961	45,666	0.15	203,000	203,000	0	0
Training Workshops (Kunming City/ Salt Lake City)	87,000	86,087		913	0.02	27,000	27,000	0	0
Website based tools development (ClimateAP/ project website)	50,000	68,482	46,000	-64,482	-1.29	51,000	51,000	0	0
Office supply and expenditure	16,000	6,436	8,000	1,564	0.10	54,000	54,000	0	0
Office Operation cost	42,500	39,663	9,950	-7,113	-0.17	295,000	295,000	0	0

Monitoring, evaluation and audit cost									
Miscellaneous									
Subtotal									
TOTAL	1,039,200	843,551	195,649						