ECOSYSTEM FUNCTION ASSESSMENT AND PARTICIPATORY MODELLING FOR COMMUNITY FOREST MANAGEMENT AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE

Mr. Wuthiwong Wimolsakcharoen

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy in Biological Sciences
Common Course
FACULTY OF SCIENCE
Chulalongkorn University
Academic Year 2019

การประเมินฟังก์ชันของระบบนิเวศและการสร้างแบบจำลองอย่างมีส่วนร่วม สำหรับการจัดการป่าชุมชนที่ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน

นายวุฒิวงศ์ วิมลศักดิ์เจริญ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาวิทยาศาสตร์ชีวภาพ ไม่สังกัดภาควิชา/เทียบเท่า
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2562

Thesis Title	ECOSYSTEM FUNCTION ASSESSMENT AND PARTICIPATORY MODELLING FOR COMMUNITY FOREST MANAGEMENT AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE
By	Mr. Wuthiwong Wimolsakcharoen
Field of Study	Biological Sciences
Thesis Advisor	Assistant Professor PONGCHAI DUMRONGROJWATTHANA, Ph.D.
Thesis Co Advisor	Guy Trébuil, Ph.D. Christophe Le Page, Ph.D.

Accepted by the FACULTY OF SCIENCE, Chulalongkorn University in Partial Fulfillment of the Requirement for the Doctor of Philosophy

.... Dean of the FACULTY OF SCIENCE
(Professor POLKIT SANGVANICH, Ph.D.)

DISSERTATION COMMITTEE

.... Chairman
(Assistant Professor NOPPADON KITANA, Ph.D.)

.... Thesis Advisor
(Assistant Professor PONGCHAI DUMRONGROJWATTHANA, Ph.D.)

.... Thesis Co-Advisor
(Guy Trébuil, Ph.D.)

.... Thesis Co-Advisor
(Christophe Le Page, Ph.D.)

.... Examiner
(Associate Professor SASITORN POUNGPARN, Ph.D.)

.... Examiner
(Assistant Professor WICHASE KHONSUE, Ph.D.)

.... External Examiner
(Warong Naivinit, Ph.D.)

วุฒิวงศ์ วิมลศักดิ์เจริญ : การประเมินฟังก์ชันของระบบนิเวศและการสร้างแบบจำลองอย่างมีส่วนร่วมสำหรับการจัดการป่าชุมชนที่ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน. (ECOSYSTEM FUNCTION ASSESSMENT AND PARTICIPATORY MODELLING FOR COMMUNITY FOREST MANAGEMENT AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE) อ.ที่ปรึกษาหลัก : ผศ. ดร.พงษ์ชัย ดำรงโรจน์วัฒนา, อ.ที่ปรึกษาร่วม : ดร.กีย์ เทรบุยล์,ดร.คริสตอฟ เลอ ปาจ

การจัดการป่าชุมชนเป็นหนึ่งในแนวทางบรรเทาปัญหาการตัดไม้ทำลายป่าที่เกิดขึ้นอย่างต่อเนื่องมากว่าครึ่งศตวรรษ โดยเฉพาะอย่างยิ่งในภาคเหนือของประเทศไทย การมีส่วนร่วมในการจัดการป่าชุมชนเป็นสิ่งสำคัญที่จะก่อให้เกิดการตรวจสอบและปรับปรุงสถานภาพ รวมทั้งหลีกเลี่ยงปัจจัยเสี่ยงที่จะทำให้ระบบนิเวศป่าชุมชนเสื่อมโทรมในอนาคต ปัจจุบันการประยุกต์ใช้กระบวนการสร้างแบบจำลองอย่างมีส่วนร่วม (participatory modelling) ในการจัดการทรัพยากรอย่างยั่งยืนได้รับความนิยมเพิ่มขึ้นทั่วโลก แต่ยังคงมีการใช้อย่างจำกัดในบริบทการจัดการป่าชุมชน โดยเฉพาะอย่างยิ่งในประเด็นการมีส่วนร่วมหลายระดับ (ตั้งแต่ระดับตำบล อำเภอ ไปจนถึงระดับจังหวัด) งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อประเมินสถานภาพป่าชุมชนผ่านฟังก์ชันของระบบนิเวศที่หมู่บ้านทั้ง 7 แห่งของตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน และใช้กระบวนการสร้างแบบจำลองและสถานการณ์จำลองอย่างมีส่วนร่วมเพื่อส่งเสริมการบูรณาการความรู้และสร้างความร่วมมือในการจัดการป่าชุมชนระดับตำบล

ผลการศึกษาพบไม้ต้น 67 ชนิด, สิ่งมีชีวิตในดิน 18 อันดับ, เห็ดป่า 105 ชนิด และของป่า 183 ชนิด โดยที่ผักหวานป่า ไข่มดแดง และเห็ดกินได้จัดเป็นของป่า 3 ชนิดหลักในพื้นที่ศึกษานี้ ซึ่งมีผลิตภาพ (productivity) 2, 12 และ 2 กิโลกรัม/เฮกตาร์/ปีตามลำดับ ผลการประเมินสถานภาพระบบนิเวศป่าชุมชนอย่างมีส่วนร่วมพบว่า คะแนนสถานภาพทั้ง 7 หมู่บ้านอยู่ในช่วงตั้งแต่ 233 ถึง 322 คะแนนจากคะแนนเต็ม 500 คะแนน โดยสถานภาพป่าชุมชนของหมู่ที่ 3 อยู่ในระดับ "ดี" ในขณะที่สถานภาพป่าชุมชนของหมู่บ้านอื่น ๆ อยู่ในระดับ "ปานกลาง" อย่างไรก็ตามป่าชุมชนของทุกหมู่บ้านยังคงมีความเสี่ยงที่จะเสื่อมโทรมได้ในอนาคต หลังจากนั้นได้ใช้กระบวนการสร้างแบบจำลองเพื่อนคู่คิด (Companion Modelling) ร่วมกับผู้มีส่วนเกี่ยวข้องจำนวน 48 คน ผลการศึกษาพบว่ากระบวนการสร้างแบบจำลองเพื่อนคู่คิดผ่านแบบจำลองและสถานการณ์จำลอง จำนวน 2 รอบ (sequences) สามารถกระตุ้นการบูรณาการองค์ความรู้ทางวิทยาศาสตร์-ท้องถิ่นผ่านการแลกเปลี่ยนแนวความคิด ความรู้ และประสบการณ์ระหว่างผู้มีส่วนเกี่ยวข้องกับคณะนักวิจัย อีกทั้งยังสนับสนุนการตัดสินใจร่วมกันของผู้มีส่วนเกี่ยวข้องในการจัดการป่าชุมชนระดับตำบล โดยผู้มีส่วนเกี่ยวข้องได้ร่วมกันกำหนดแผนปฏิบัติการจัดการป่าชุมชนระดับตำบล ได้แก่ การสร้างแนวกันไฟ และแนวทางการแก้ไขปัญหาการลักลอบเก็บของป่าโดยคนนอกชุมชน

สรุปได้ว่าการประเมินสถานภาพระบบนิเวศป่าชุมชนอย่างมีส่วนร่วมทำให้เกิดความเข้าใจในสถานภาพระบบนิเวศป่าชุมชนร่วมกันและการใช้กระบวนการสร้างแบบจำลองและสถานการณ์จำลองอย่างมีส่วนร่วมสามารถส่งเสริมความร่วมมือในการจัดการป่าชุมชน ระดับตำบล ในการนำแผนงานและแนวทางที่กำหนดขึ้นไปสู่การปฏิบัตินั้น การสนทนากลุ่มและการใช้เกมและสถานการณ์จำลองยังคงมีความจำเป็นที่จะต้องจัดขึ้นเพิ่มเติมอีกในอนาคต โดยเพิ่มความหลากหลายของผู้มีส่วนเกี่ยวข้อง โดยเฉพาะอย่างยิ่งเยาวชนในพื้นที่ กระบวนการประเมินสถานภาพและสร้างแบบจำลองอย่างมีส่วนร่วมในกรณีศึกษานี้จะเป็นประโยชน์ต่อการพัฒนาความร่วมมือในการจัดการป่าชุมชนระดับที่สูงขึ้น (เช่น อำเภอเวียงสาหรือจังหวัดน่าน) หรือนำไปประยุกต์ใช้ในพื้นที่อื่น ๆ ที่มีปัญหาคล้ายคลึงกัน

สาขาวิชา	วิทยาศาสตร์ชีวภาพ	ลายมือชื่อนิสิต ....
ปีการศึกษา	2562	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

5572836023 : MAJOR BIOLOGICAL SCIENCES
KEYWORD: COLLABORATIVE MODELLING, COMMUNITY-BASED FOREST MANAGEMENT, COMPANION MODELLING (ComMod), ECOSYSTEM ASSESSMENT, ECOSYSTEM SERVICE

Wuthiwong Wimolsakcharoen : ECOSYSTEM FUNCTION ASSESSMENT AND PARTICIPATORY MODELLING FOR COMMUNITY FOREST MANAGEMENT AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE. Advisor: Asst. Prof. PONGCHAI DUMRONGROJWATTHANA, Ph.D. Co-advisor: Guy Trébuil, Ph.D., Christophe Le Page, Ph.D.

Community forest management (CFM) is one way used to mitigate deforestation and forest degradation which have been occurring for more than half a century, particularly in northern Thailand. The collaboration in CFM, especially at multiple scales (e.g. subdistrict, district, or provincial levels) is essential to improve a forest ecosystem status and avoid forest degradation risks in the future. Recently, integrative and participatory modelling methodologies, specifically the Companion Modelling (ComMod), have been implemented in the context of sustainable common-pool resource management in several regions of the world. However, the application of this approach in CFM across institutional scales has still been challenging. Therefore, this research aimed to assess community forest ecosystem functions at the seven villages of Lainan Subdistrict, Wiang Sa District, Nan Province, and conduct a participatory modelling and simulation process to promote collaborative CFM at the subdistrict scale.

Ecologically conventional and participatory assessments of ecosystem functions were performed to assess community forest ecosystem status. Lainan's community forests have officially been operating for nearly 50 years. There were 67 tree species, 18 orders of soil fauna, 105 wild mushroom species, and 183 non-timber forest products (NTFPs). Among these diverse NTFPs, *Melientha suavis*, *Oecophylla smaragdina*'s queen broods, and wild edible mushrooms were identified as the three common NTFPs at this site with the productivity of 2, 12, and 2 kg/ha/y, respectively. The results from the participatory assessment showed that the forest status scores of all villages ranged from 233 to 322 of 500 points. Only village 3 obtained "good" for its community forest ecosystem status while the other villages' status was "moderate". However, all villages were still facing forest degradation risks. Following this preliminary diagnostic analysis, a ComMod process including two participatory modelling and simulation sequences was implemented with 48 local stakeholders. The results showed that this iterative and evolving process could stimulate the integration of scientific and local knowledge through the exchanges of viewpoints, perceptions, knowledge, and experiences among local stakeholders, as well as between them and researchers. Moreover, it also supported collective decision-making among them as two CFM collective action plans at the subdistrict scale were proposed, including establishment of firebreaks and management options to deal with the over-harvesting of non-timber forest products by outsiders.

In summary, the participatory assessment generated a shared understanding on the community forest ecosystem status and the participatory modelling and simulation approach supported collaborative CFM at the subdistrict scale. To translate the proposed CFM plans into actual collective action, focus group discussions and further participatory gaming and simulation sessions need to be enhanced by enrolling diverse stakeholders across generations, especially young local villagers. The participatory assessment and modelling process used in this case study would be useful to improve collaborative CFM at higher institutional scales or at other sites facing the similar problems.

Field of Study:	Biological Sciences	Student's Signature ....
Academic Year:	2019	Advisor's Signature ....
		Co-advisor's Signature ....
		Co-advisor's Signature ....

ACKNOWLEDGEMENTS

I wish to express my profound gratitude and honest appreciation to Dr. Guy Trébuil, Asst. Prof. Dr. Pongchai Dumrongrojwatthana, and Dr. Christophe Le Page for serving as my Ph.D. supervisors. Their critiques were very valuable and helpful for achieving this research. Dr. Guy Trébuil made a particular effort to provide me with excellent guidance, technical support, and everlasting patience and encouragement during the whole length of my study. Asst. Prof. Dr. Pongchai Dumrongrojwatthana made a special attempt to arrange for the financial contributions.

My sincere thanks are due to Asst. Prof. Dr. Noppadon Kitana who serves as the dissertation committee chairman, as well as Assoc. Prof. Dr. Sasitorn Poungparn, Asst. Prof. Dr. Wichase Khonsue, and Dr. Warong Naivinit for serving as the dissertation committee members.

I am highly thankful to Dr. François Bousquet for his very useful guidance and tireless technical support to implement a computer-assisted role-playing game in this case study, as well as Dr. Pierre Bommel for his kind guidance to develop the UML diagrams. The INNOVATION Joint Research Unit and the GREEN Research Unit at Centre de coopération internationale en recherche agronomique pour le développement (Cirad) are also recognized for their support during my stay in Montpellier, France.

Asst. Prof. Dr. Nipada Ruankaew Disyatat from the Department of Biology and Asst. Prof. Dr. Jittra Piapukiew from the Department of Botany of Chulalongkorn University, and the Soil Analysis Laboratory at the Faculty of Environment of Kasetsart University are also acknowledged for their technical support and suggestions for data analyses.

Subdistrict Administrative Organization staff members and Lainan local villagers, especially the workshop participants, are sincerely appreciated for their warm welcome and excellent cooperation throughout this research, as well as Centre of Learning for the Region (CLNR), Chulalongkorn University for facilitating the accommodations in the field. Members of the Tropical Ecology and Natural Resource Management (TENRM) Research Laboratory are also very appreciated for their kind assistance, particularly in conducting the field workshop.

The financial support received from the Royal Government of Thailand Scholarship under the Development and Promotion of Science and Technology Talents (DPST) Project, the 90th Anniversary of Chulalongkorn University Scholarship, the Sponsorship for Graduate Student Research under Chulalongkorn University Academic Network in the Region (CU-ANR-60-01), and the Plant Genetic Conservation Project under the Royal Initiative for Her Royal Highness Princess Maha Chakri Sirindhorn are deeply acknowledged.

Finally, I gratefully thank my parents and my beloved brother and sister for their enthusiasm and understanding they gave to me.

Wuthiwong Wimolsakcharoen

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LIST OF ABBREVIATIONS

ABM	Agent-based model
ACS	Aboveground carbon storage
CFM	Community forest management
ComMod	Companion modelling
CORMAS	Common-pool resource and multi-agent system
cRPG	Computer-assisted role-playing game
CWD	Cross wood debris
DBH	Diameter at breast height (of a forest tree)
H′	Shannon-Wiener’s index of species diversity
INRM	Integrated natural resource management
IVI	Important value index
MAS	Multi-agent system
NRM	Natural resource management
NTFP	Non-timber forest product
ODD	Overview, design concepts, and details
PARDI	Problem(s), actors, resources, dynamics, and interactions
RAWES	Rapid assessment of wetland ecosystem services
RPG	Role-playing game
SAO	Subdistrict administrative organization
SES	Social-ecological system
TESSA	Toolkit for ecosystem service site-based assessment
UML	Unified modelling language
V	Village

CHAPTER I
INTRODUCTION

1.1 Rationale

Deforestation and forest degradation have been an important environmental problem for more than half a century, especially in northern Thailand (Royal Forest Department, 2018). One way to mitigate this problem is community forest management (CFM), an active protection and utilization of a forest ecosystem by a local community (Salam *et al.*, 2006; Nayak and Berkes, 2008). Due to the government policy on logging concessions issued in 1963, forest encroachment still occurs in several areas including in community forests. This problem negatively affects the community forest ecosystem functions (e.g. food, raw materials, medicinal resources) which are linked to the well-being of local people (e.g. food security, income generation). Based on a review of previous Thailand's community forest research, 77% of the past investigations on this subject mainly focused on social science aspects. This showed the lack of ecological studies, especially the assessment of community forest ecosystem status which is important in CFM planning. The collaboration in CFM, particularly at multiple scales (e.g. subdistrict, district, provincial, or regional levels) is essential to improve a forest ecosystem status and avoid any forest degradation risks in the future (Mohammed *et al.*, 2017). The author hypothesized that the research on adaptive management and knowledge integration (scientific and local knowledge) among stakeholders for co-learning and improving the interactions between ecological and socio-economic dynamics of a community forest ecosystem can be used to improve the poor current situation in community forestry. Recently, integrative (including ecological and socio-economic aspects) and participatory (with heterogeneous stakeholders) modelling approaches have been implemented in the context of sustainable common-pool renewable resource management. Among diverse approaches in this participatory modelling family, Companion Modelling (ComMod) has been implemented in several regions of the world including Thailand to facilitate the collective understanding of the social-ecological systems' complexity and to support collective decision-making and action for integrated natural resource management (INRM) (Voinov and Bousquet, 2010; Étienne, 2014).

The research was conducted at the seven community forests of Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand (Figure 1.1). Lainan Subdistrict covers 125 km^2 and with an average current population density of lowland Thai people of 28 inhabitants/km^2 (Department of Provincial Administration, 2017). The majority of the working population farms their own land, with farm sizes ranging from 1.6–11.2 ha. A few villagers are landless, and several settlers are government officers. More details about the study site are shown in sections 4.1 and 4.2 regarding carrier and information functions of the Lainan's community forest ecosystem, respectively.

1.2 Research questions

The general research questions of this study were as follows:

(i) What is the current status of the Lainan's community forests based on the participatory assessment of the community forest ecosystem functions?

(ii) Can a participatory modelling approach promote scientific and local knowledge integration, and increase the adaptive capacity of local villagers to better manage their community forest collectively at multiple levels?

1.3 Research objectives

Based on the two general research questions, the two general and complementary objectives of this action research were:

(i) to assess community forest ecosystem functions at the seven villages of Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand; and

(ii) to construct and implement a participatory modelling process with local stakeholders in order to promote collaboration in CFM at the subdistrict scale.

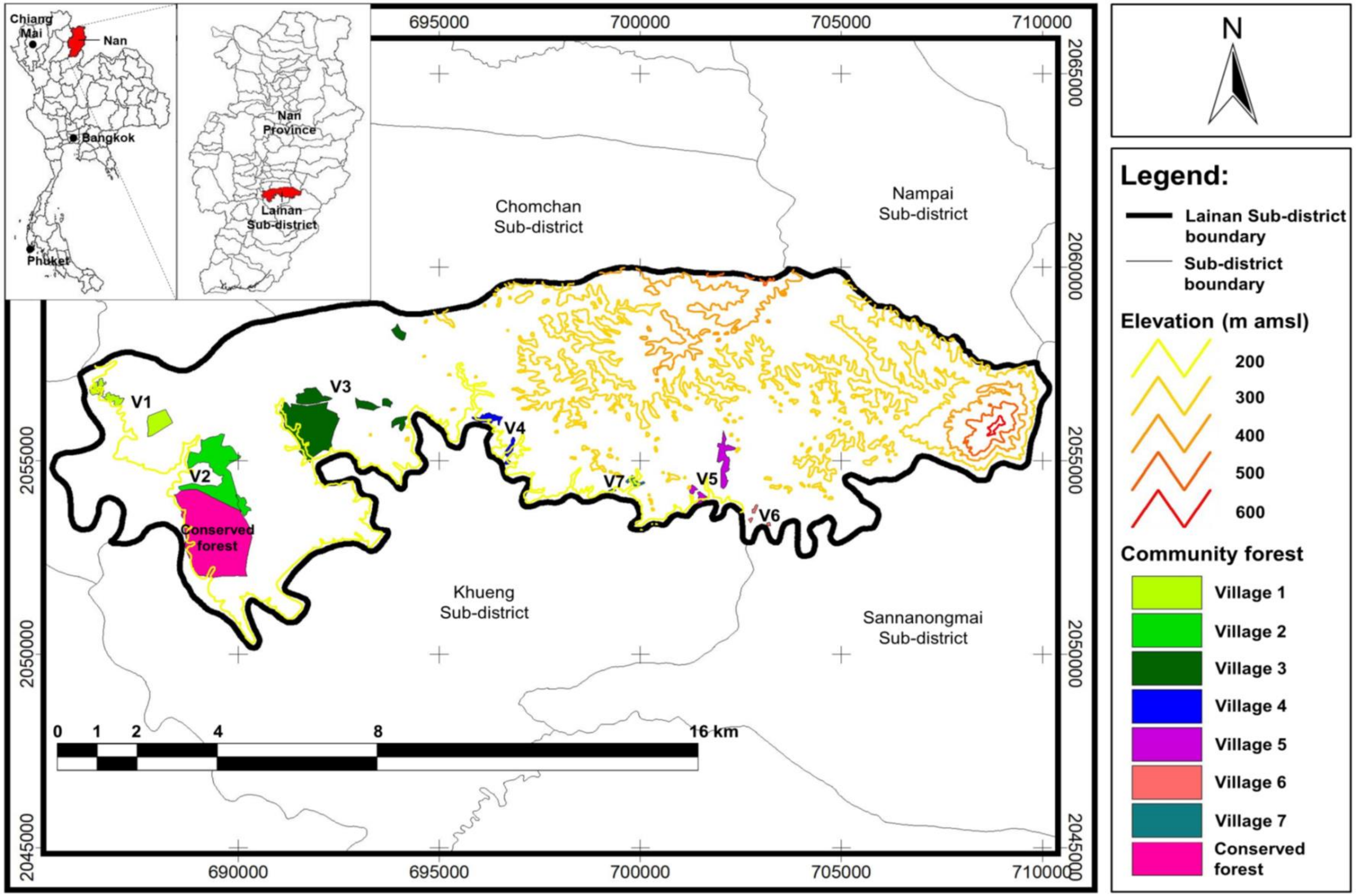

Figure 1.1: Location of the study site at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

1.4 Conceptual framework

Figure 1.2 illustrates the schematic conceptual framework of this research, which was composed of three main successive phases as follows: (i) ecological field surveys to investigate five main categories of community forest ecosystem functions classified into ecological (production, regulation, habitat, and carrier ones) and social (information ones) modules, (ii) participatory assessment of community forest socio-ecological status, and (iii) participatory modelling and simulation process. The first two main phases corresponded to the first research objective while the participatory modelling and simulation process corresponded to the second research objective.

1.5 Dissertation structure

Following a presentation of the related theoretical concepts relying on a review of the literature (CHAPTER II), the selected research methodology is described (CHAPTER III). The subsequent section (CHAPTER IV) presents the proceedings and outcomes of the ecological field investigations in the Lainan's community forests based on the five main categories of ecosystem functions. The presentation of the Lainan's community forest ecosystem status based on the participatory assessment is presented (CHAPTER V) followed by the outcomes of the participatory modelling and simulation process, their discussion, and the CFM action plan at the subdistrict scale (CHAPTERS CHAPTER VI and CHAPTER VIICHAPTER VI). Finally, conclusion and perspectives to enhance the level of stakeholder participation and to translate the proposed CFM plans at the subdistrict scale into actual collective actions are proposed (CHAPTER VIII).

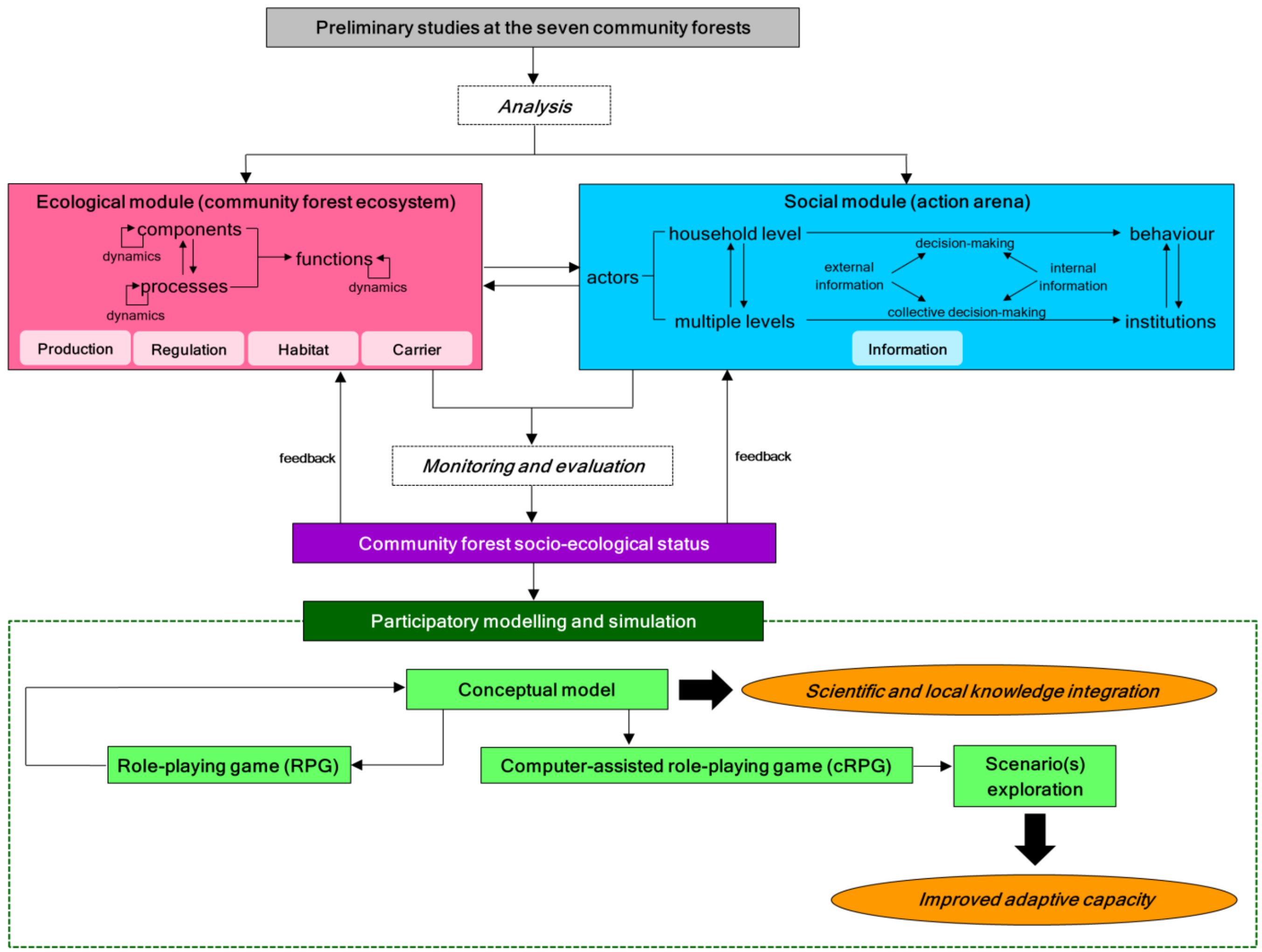

Figure 1.2: Conceptual framework of the research based on the Companion Modelling (ComMod) approach.

CHAPTER II
LITERATURE REVIEW

2.1 Community forestry and its current situation in Thailand

2.1.1 Community forestry and its complexity

A community forest is generally understood as an active conservation/protection of a forest ecosystem and its utilization by a local community (Salam *et al.*, 2006; Nayak and Berkes, 2008). In Thailand, it refers to social aggregation at a community (village) scale for renewable resource management and utilization of a forest ecosystem based on their traditional knowledge (Chamarik *et al.*, 1993). Based on the first Thailand's community forest bill promulgated in 2019, a community forest is defined as "the forest areas located outside conserved forests (e.g. national parks, wildlife sanctuaries), and approved to be a community forest under the collaboration between the local community and government for conservation, restoration, management, and sustainable utilization of natural resources, environment and biodiversity".

A community forest is composed of multiple subsystems and internal components (both ecological and social) within these subsystems interacting at multiple levels. In other word, a community forest can be seen as a complex social-ecological system (SES) where ecological processes and human activities are interdependent, co-evolve, and are linked through various interactions and interconnections (Ostrom, 2009; Folke *et al.*, 2010).

2.1.2 State of the art on Thailand's community forestry research

Based on a search of 292 references on Thailand's community forestry in the Thai Library Integrated System (ThaiLIS) database (ThaiLIS Digital Collection, 2015), the results showed that 88% of the total studies focused on a single dimension of social (77%) or ecological (11%) aspects, and only 13% of the total studies dealing with both social and ecological aspects in a single document. However, there has not been a real integration of social-ecological aspects in those previous studies as the dimensions of human and environment were separately investigated without examining their interactions. The results showed that previous research on community forestry in Thailand mainly focused on a single dimension of social sciences. This indicated that integrated social-ecological studies based on the concept of SES are still innovative for future research in this field.

2.2 Community forest ecosystem functions

Similar to other forest ecosystems, a community forest ecosystem plays an important role in providing several ecosystem functions, defined as "the capacity of natural processes and components to provide ecosystem goods and services which satisfy human needs directly and indirectly" (De Groot *et al.*, 2002; Nadrowski *et al.*, 2010).

Based on De Groot *et al.* (2002) and De Groot (2006), there are five main categories of community forest ecosystem functions including regulation, habitat, production, information, and carrier ones. Following these five main categories, 33 community forest ecosystem functions are described in Table 2.1.

Table 2.1: Typology of community forest ecosystem functions (adapted from De Groot *et al.*, 2002; De Groot, 2006).

Main category	Community forest ecosystem function	Component or process	Example of good and service
Regulation functions: maintenance of essential ecological processes and life support systems	1. Gas regulation	- Bio-geochemical cycles (e.g. CO_2/O_2 balance, etc.)	- Maintenance of (good) air quality - Influence on climate (see also function 2)
	2. Climate regulation	- Land cover (the complex interactions of topography, vegetation, albedo (the fraction of incident electromagnetic radiation reflected by a surface, especially of a celestial body), as well as the configuration of, for example, lakes, rivers, and bays) - Biological mediated processes which influence on climate - Greenhouse gases balance (including carbon sequestration)	- Maintenance of a favorable climate (temperature, precipitation, etc.)
	3. Disturbance prevention	- Vegetative structure can alter potentially catastrophic effects of storms, floods, and droughts through its storage capacity and surface resistance.	- Safety of human life and human constructions - Flood prevention

Table 2.1 (cont').

Main category	Community forest ecosystem function	Component or process	Example of good and service
Regulation functions (cont')	4. Water regulation	- Role of land cover in regulating runoff and river discharge	- Maintenance of 'normal' conditions in a watershed and not the prevention of extreme hazardous events such as natural irrigation and drainage - Provision of a medium for transportation
	5. Water supply	- The performance of vegetation cover and (soil) biota which influence on the filtering-function - Topography and sub-surface characteristics of the involved ecosystem which influence on the retention and storage	- Provision of water for consumptive use (e.g. drinking, irrigation, etc.) (by households, agriculture, industry)
	6. Soil retention	- Role of vegetation cover and its root system in soil retention	- Maintenance of arable land - Prevention of damage from erosion/siltation
	7. Soil formation	- Weathering/disintegration of rock which gradually becomes fertile through the accretion of animal and plant organic matter and the release of minerals - Accumulation of organic matter	- Maintenance of productivity on arable land - Maintenance of natural productive soils
	8. Nutrient regulation	- Role of biota in storage and re-cycling of nutrients	- Maintenance of healthy soils - Influence on gas-, climate-, and water-regulation functions (see also functions 1, 2, and 4)
	9. Waste treatment	- Role of vegetation and biota in removal or breakdown of xenic nutrients and compounds	- Pollution control/detoxification - Filtering of dust particles
	10. Pollination	- Role of biota (wild pollinator species including insects, birds, and bats) in movement of floral gamete	- Pollination of wild plant species - Pollination of crops
	11. Biological regulation*	- Millions of years of evolutionary processes leading to many interactions and feedback mechanisms in biotic communities of natural ecosystems - Population control through trophic-dynamic relations	- Control of pests and diseases (biological control) - Reduction of herbivory (crop damage) - Ecological relationships
	12. Ecological succession*	- A series of different plant communities, and associated animals and microbes successively occupy and replace each other over time in a particular ecosystem or landscape location following a disturbance to that ecosystem	- Maintenance of ecosystem structures and processes (in a climax community)

Table 2.1 (cont').

Main category	Community forest ecosystem function	Component or process	Example of good and service
Habitat function: providing habitat (suitable living space) for wild plant and animal species	13. Refuge and nursery	- Suitable living space for wild plants and animals - Suitable reproduction habitat	- Maintenance of biological and genetic diversity (and, thus, the basis for most other functions) - Maintenance of commercially harvested species
Production functions: provision of natural resources	14. Food	- Conversion of solar energy into edible plants and animals	- Non-timber forest products (NTFPs) (e.g. vegetables, mushrooms, etc.) - Small-scale subsistence farming and aquaculture
	15. Raw materials	- Conversion of solar energy into biomass for human construction and other uses	- Biotic resources which are taken into account for building and manufacturing (e.g. timber products, strong fibers, biochemical or biodynamic compounds), and energy resources (e.g. fuelwood) - Animal-feed (e.g. grass, leaves, krill)
	16. Genetic resources	- Genetic material and evolution in wild plants and animals	- Improved crop resistance to pathogens and pests
	17. Medicinal resources	- Variety in (bio)chemical substances in, and other medicinal uses of natural biota	- Drugs and pharmaceuticals
	18. Ornamental resources	- Variety of biota in natural ecosystems with (potential) ornamental uses	- Resources for fashion and clothing (animal skins and feathers), handicraft (e.g. wood and ebony for carving), objects of worship (i.e. products associated with cultural, tribal, and religious ceremonies), jewelry, wild animals and plants as the collections for zoological and botanical gardens, and souvenirs as collector's items (e.g. furs, feathers, ivory, orchids, butterflies, aquarium fish, shells, etc.)

Table 2.1 (cont').

Main category	Community forest ecosystem function	Component or process	Example of good and service
Information functions: providing opportunities for cognitive development	19. Aesthetic information	- Attractive landscape features (houses near national parks or with a nice river view)	- Enjoyment of scenery (scenic roads, housing, etc.)
	20. Recreation	- Variety in landscapes with (potential) recreational uses	- A place where people can come for rest, relaxation, refreshment, and recreation - Recreational activities, such as walking, hiking, camping, fishing, swimming, and eco-tourism
	21. Artistic information	- Variety in natural features with artistic values	- A motive and source of inspiration for books, magazines, film, photography, paintings, sculptures, folklore, national symbols, music, architecture, advertising, etc.
	22. Spiritual and religious information	- Variety in natural features with spiritual and religious values	- Spiritual and religious values placed in nature (e.g. worship of holy forests, trees, or animals)
	23. Historic information	- Variety in natural features with historic values	- Heritage value of natural ecosystems and features
	24. Research and education	- Variety in nature with research and educational values	- Nature studies (eco-tourism) - Field laboratories for scientific research
	25. Cultural creation	- Variety in natural features with cultural values	- Culture - Management strategies
Carrier functions: providing a suitable substrate or medium for human activities and infrastructure	26. Habitation	- Depending on the specific land use type, different requirements are placed on environmental conditions (e.g. soil stability and fertility, air and water quality, topography, climate, geology, etc.)	- Living space (ranging from small settlements to urban areas)
	27. Agriculture/ Cultivation		- Food and raw materials from cultivated land and aquaculture - Farming
	28. Energy-conservation		- Energy-facilities (solar, wind, water, etc.)
	29. Mining		- Minerals, oil, gold, etc.
	30. Waste disposal		- Space for solid waste disposal
	31. Transportation		- Transportation by land and water
	32. Tourism-facilities		- Tourism-activities (outdoor sports, etc.)
	33. Reforestation*		- Forest land

*ecosystem functions proposed by the author extended from De Groot *et al*. (2002) and De Groot (2006).

All the ecosystem functions result from interactions among the characteristics, structures, and processes constituting the physical, chemical, and biological exchanges in a community forest ecosystem (Banerjee *et al.*, 2013). These processes provide benefits called 'ecosystem services' to local people, as shown in Figure 2.1.

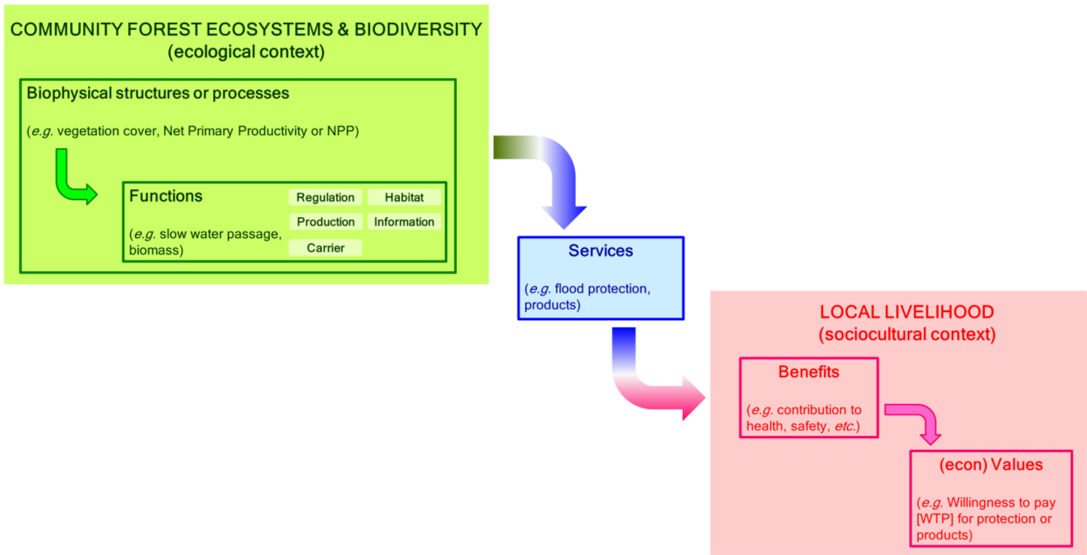

Figure 2.1: Ecosystem service cascade linking ecosystems and human well-being in a social-ecological system (SES) (adapted from De Groot *et al.*, 2010).

2.3 Assessment of community forest ecosystem functions

2.3.1 Importance of ecosystem assessment

After the publication of Millennium Ecosystem Assessment (2005), there have been a rapidly growing number of studies on ecosystem functions including their assessment (Meyer *et al.*, 2015). The quantification of ecosystem functions underlying ecosystem services is necessary to support local policy- and decision-making in community forest management (CFM) and at the same time foster human well-being (Pandeya *et al.*, 2016).

Engagement of local people in the process of quantifying ecosystem functions can lead to rapid decisions to avoid or solve the key degradation threats on their community forest ecosystem, empower local communities for improved CFM, and promote locally based (long-term) monitoring of their community forest ecosystem status (Danielsen *et al.*, 2009; Birch *et al.*, 2014; Peh *et al.*, 2016).

2.3.2 State of the art on the tools used for ecosystem assessment

Several ecosystem assessment tools, such as Assessment and Research Infrastructure for Ecosystem Services (ARIES) (Bagstad *et al.*, 2011), cooperate Ecosystem Services Review (ESR) (Hanson *et al.*, 2012), Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) (Sharp *et al.*, 2018), Multi-scale Integrated Models of Ecosystem Services (MIMES) (Boumans *et al.*, 2015), Rapid Assessment of Wetland Ecosystem Services (RAWES) (McInnes and Everard, 2017), and Toolkit for rapid assessment of Ecosystem Service Site-based Assessment (TESSA) (Peh *et al.*, 2013) were developed and used to evaluate the ecosystem functions/services for diverse purposes in various type of ecosystems. To determine which tools are suitable for ecosystem assessments, several characteristics including time requirements, affordability (cost), labour demand, requirement of specialist technical knowledge and computational skills, quantifiability, and multiplicity of ecosystem functions/services need to be considered (Bagstad *et al.*, 2013; Peh *et al.*, 2013). These characteristics of several above-mentioned ecosystem assessment tools are summarized in Table 2.2.

Table 2.2: Characteristics of ecosystem assessment tools (adapted from Bagstad *et al*., 2013; Peh *et al*., 2013).

Ecosystem assessment tool	Characteristics of ecosystem assessment tools						
	Time-saving efficiency	**Affordability (cost)**	**Labour demand**	**Specialist technical knowledge**	**Requirement of computational skills**	**Quantifiability**	**Multiplicity of ecosystem functions (or services)**
ARIES[1]	Low	Low	Low	Low–High	Moderate/High	High (Quantitative)	Low
ESR[2]	High	High	Low	High	High	Low (Qualitative)	Low
InVest[3]	Low/Moderate	High	Low	High	High	High (Quantitative)	Moderate
MIMES[4]	Low	High	Low	High	High	High (Quantitative)	n/a
RAWES[5]	High	Low	Low	Low	Low	Low (Qualitative)	High
TESSA[6]	High	Low	Low	Low	Moderate	High (Quantitative)	Low
This case study (see more details in CHAPTER V)	High	Low	Low	Low	Low	Moderate (Both quantitative and qualitative)	Moderate

[1]Assessment and Research Infrastructure for Ecosystem Services.
[2]Ecosystem Services Review.
[3]Integrated Valuation of Ecosystem Services and Tradeoffs.
[4]Multi-scale Integrated Models of Ecosystem Services
[5]Rapid Assessment of Wetland Ecosystem Services
[6]Toolkit for rapid assessment of Ecosystem Service Site-based Assessment

As most of the ecosystem assessment tools, including ARIES, ESR, InVest and MIMES, required high computational skills and specialist technical knowledge, it could be difficult to use them in a participatory approach engaging local people in the assessment of their community forest ecosystem (Table 2.2). Local participation in the assessment of community forest ecosystem promotes self-monitoring by local people leading to improved CFM becoming more relevant locally and hence sustainable (Danielsen *et al.,* 2009). Several recent publications also proved that integrating local people, specifically those who will be affected by CFM, into the CFM process creates several positive impacts. For example, the objectives of such conservation/protection are easier to be achieved, and these local people are also more likely to express positive attitudes towards the conservation/protection of their community forests (Dolisca *et al.*, 2006; Gurney *et al.*, 2016). Using RAWES and TESSA seems to be more applicable in the participatory assessment due to their low requirement of such computational skills and specialist technical knowledge. However, RAWES has a very limited ability to quantify ecosystem functions, while a limited number of ecosystem functions/services (not all the main categories of ecosystem functions/services are taken into account) are covered in TESSA (Table 2.2). These indicate a critical situation as there is a lack of ecosystem assessment tool suitable to be used in an integrated participatory approach, and covering every main category of ecosystem functions.

2.4 Participatory modelling approaches in natural resource management

Recently, stakeholder participation has become common in several management-oriented areas of science, especially environmental assessment or modelling (Voinov and Bousquet, 2010; Voinov *et al.*, 2016). This trend is related to (i) a universal drive towards greater decentralization and people's participation, (ii) a growing grassroots demand for public engagement in environmental planning and decision support, (iii) a realization by decision-makers that new management or policy recommendations are less likely to be acted on if stakeholders are excluded from the policy development process, (iv) a realization by modellers that the public can provide considerable knowledge, labour and skills, and may even help mobilize funding, and (v) the fast-growing and easy access to technical capacities that enable quicker and broader public involvement, notably through the internet and Web 2.0 (Voinov *et al.*, 2016). On one hand the efficiency of the participatory process depends on social relations between stakeholders, their ability to communicate and exchange information, their knowledge, but also skills and methods to assist them in doing that. On the other hand there is a clear need for technical, analytical and modelling tools and software that can be used in this process. Over the last decade progress has been made both on the social and technical aspects, and this section aims at presenting some of these achievements. Different groups of researchers have advanced in parallel, developing and applying specific methodologies, which are based on similar principles but focus on different parts of the process. This review focused on participatory modelling methodologies, a generic term to define "the use of modelling in support of a decision-making process that involve stakeholders" (Voinov and Bousquet, 2010). Voinov *et al.* (2016) proposed seven general domains or 'components' in the modelling processes (Figure 2.2) as follows:

(i) *Scoping and abstraction:* selection of the model or of the topic itself, selection of stakeholders (including self-selection). Stakeholder involvement at this vitual formative stage in the modelling process reflects the principle of citizen engagement into the participatory design and analysis.

(ii) *Envision and goal-setting:* stakeholders can identify the conceptual basis of the model, select the parameters/variables to include in the model, and possible modify the topics, concepts, critical issues, etc.

(iii) *Model formation:* identify the parameters and variables to be used, select the model formulation and design methods, select analytical methods and tools.

(iv) *Collection of original data and cross-checking of expert data:* stakeholders are involved in this component as citizen scientists.

(v) *Apply model to decision-making*.

(vi) *Evaluation of the outputs (or impact evaluation):* stakeholders are often included in this component – participants are asked to evaluate the specific and immediate outputs of a model. This typically involves evaluating technical measures of model performance.

Evaluation of the outcomes (or effect evaluation): stakeholders are often included in this component – participants are asked to evaluate the long-term, broader-scale results or outcomes following a participatory modelling process.

(vii) *Facilitation of transparency of the process:* public evaluation of the participatory modelling process. Stakeholders are central in this component.

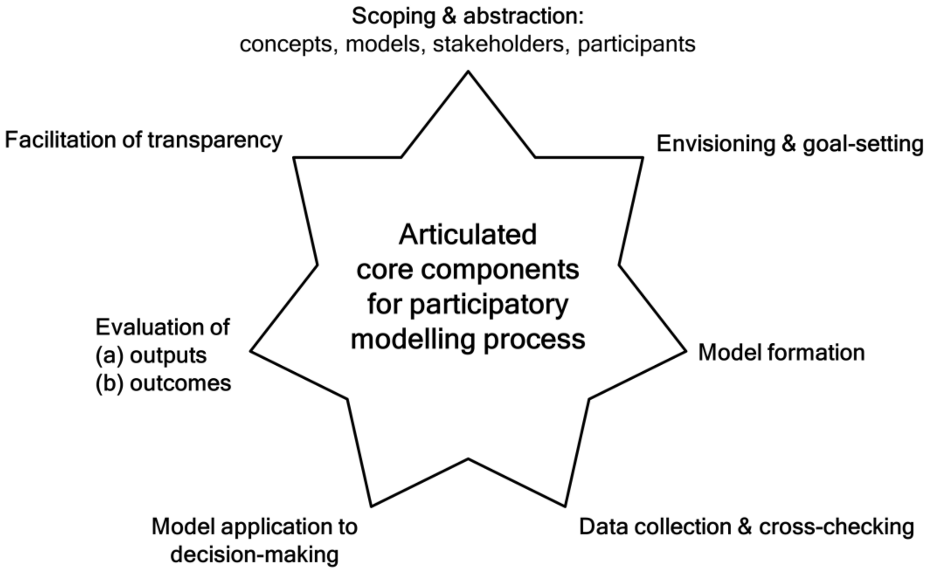

Figure 2.2: Components of the participatory modelling process. The sequencing of components is adaptable to the evolving needs presented by the issue(s) being investigated (and modelled) and those of the participants and stakeholders. The components are susceptible to being revisited as necessary. (Source: Voinov *et al*., 2016).

According to Voinov and Bousquet (2010), there are five different participatory modelling approaches used in natural resource management (NRM) as follows:

(i) *Group Model Building* is a method that mostly used in business applications but also for NRM. It is based less on formal modelling and more on Causal Loop Diagrams and similar visual tools. It may be taken to the next step using systems dynamics tools (e.g. DYNAMO, Stella, Vensim) or Delphi. It involves a group of people, stakeholders, in one or more sessions to build the conceptual model. A facilitator who has experience with the method helps the group to build the model, usually staying neutral of the content. The modelling is considered as a process of building mutual understanding, defining terms and notions, and sharing experiences. A Group Model Building session can start with reading a concept learning history, or even an unsorted pile of interviews, facts and narratives. During and after the session the so-called 'Learning History' is extended and then prepared for further implementation in decision-making.

(ii) *Mediated Modelling* is not very different from the Group Model Building, except it does focus primarily on environmental applications. It usually builds on system dynamics, that is Stella. The use of icon-based software increases the transparency of the process. The modelling process is used to translate individual viewpoints into a common language, which is an important element of any mediation effort. Individual stakeholders collectively guide the development of a dynamic model, linking their different viewpoints about the system into a coherent whole. The process assumes a quite intensive participation of stakeholders in the process and usually requires a high level of commitment.

(iii) *Companion Modelling* (ComMod) is the brand usually associated with a process involving the stakeholders in the co-design of a conceptual model "to open the black box of the model" and encourage the use of the model by its co-designers. Its implementation as a role-playing game (RPG), used to validate the model, is often associated to a computer agent-based model (ABM) "playing the game" *in silico* to explore possible future scenarios in a time efficient fashion. ComMod is based on three major principles of model co-construction to achieve a shared representation of the situation, transparency of hypotheses, and adaptivity/flexibility to meet the stakeholders evolving demand along a learning process.

(iv) *Participatory Simulation* is developed for NRM based on the implementation of a RPG and a computer ABM. It allows people to play games over the internet, also supporting chats. One advantage of this technology is that every decision and interaction is registered for further analyses. However, as it is used at present, the modelling itself is not participatory as the settings and the rules of the games cannot be modified by the stakeholders. In other words, the stakeholders participate only in simulations, not in model design and construction.

(v) *Shared Vision Planning* has been mostly developed in applied studies primarily with the US Army Corps of Engineers, when planning regulatory issues in water management had to be resolved. Consequently, most of the publications are Corps Reports and conference presentations, with hardly any peer reviewed papers available so far.

All of the five above-mentioned participatory modelling methodologies relate to the principle of collaborative learning, an approach to teaching and learning that puts learners in groups to work together on problems, complete a task, or create a product. The collaborative learning occurs through communication among the participants during a naturally social act.

Based on several earlier case studies dealing with forest ecosystems in several regions of the world (Campo *et al.*, 2009; Simon and Étienne, 2010), including northern Thailand (Ruankaew *et al.*, 2010), the ComMod approach seems to be suitable to improve CFM because it not only facilitates the collective learning process of the SES dynamics through scenario simulations, but also promotes the engagement of stakeholders in all the seven domain in the modelling process. This is why this ComMod approach was selected in this case study.

2.5 Companion Modelling (ComMod) approach

2.5.1 What is the ComMod approach?

In the family of participatory modelling methodologies, a ComMod process is a highly interactive participatory modelling and simulation set of activities used by researchers and concerned stakeholders. It is composed of several successive, iterative but evolving, sequences of activities carried out with heterogeneous stakeholders to examine a given common resource management problem, and to stimulate collective decision-making (Barreteau *et al.*, 2003a). ComMod activities aim at understanding a complex SES issue and strengthening adaptive capacity of resource managers by generating a shared representation of the problem through the exchanges of knowledge, experience, and opinions among the concerned stakeholders, facilitated by modelling and simulation tools co-designed with them (Étienne, 2014). The model corresponding to this shared representation can then simulate possible future scenarios selected by the local stakeholders to facilitate negotiation, the emergence of acceptable coordinating mechanisms, and agreed upon action plans. To foster collective learning, ComMod activities frequently rely on the synergistic effects of a RPG and a computer ABM (Bousquet *et al.*, 2002). Such participatory modelling and simulation process was implemented in several regions of Thailand, particularly in the northern upland areas, to improve the management of irrigation water at the catchment scale (Promburom and Bommel, 2005), to mitigate the risk of land degradation (Barnaud *et al.*, 2007) or a land use conflict between herders and foresters (Dumrongrojwatthana *et al.*, 2011), and also to facilitate the negotiation between a recently established national park and villagers harvesting non-timber forest products (NTFPs) (Ruankaew *et al.*, 2010).

2.5.2 Main theoretical references of the ComMod approach

There are six key theoretical frames and concepts used as references of the ComMod approach (Trébuil, 2008).

2.5.2.1 Complexity sciences

The analysis of the emergent properties at a whole SES system scale, resulting from the interactions and interconnections of its components, cannot be observed at the individual component scale. This paradigm supports the ComMod willingness to integrate various disciplines and viewpoints, and to pay importance to interactions. The complexity sciences also underline the fact that the behaviour of complex SES is nonlinear, continuously evolving, unstable, uncertain, and unpredictable. These characteristics have major implications on the ComMod choice of a suitable modelling and simulation approach to better understanding and represent a SES, and to identify what interactions govern its functioning and change, then modify them to explore through simulations how to lead the SES towards a more desired state.

2.5.2.2 Adaptive management

This concept underlines the need for a better understanding of the SES functioning to improve the adaptive capacity of the stakeholders and its self-regulation and self-organization properties. Adaptive management, a learning-based approach involving the fundamental features of learning and adaptation which lead to improved understanding of the SES and improved management based on that understanding (Williams, 2011), implies flexibility, diversity, and redundancy in regulation and monitoring activities leading to corrective responses and experiential probing of the ever changing circumstances of the SES. Although the concept of adaptive management was conceived by ecologists, they recognized that adaptive capacity is dependent on knowledge, its generation and exchange, and the ability to recognize points of intervention to construct a bank of options for NRM. Therefore, the organization of platforms to stimulate the interactions among stakeholders for generating and exchanging knowledge is required. This social process of knowledge generation and exchange may lead to a new kind of interactions and to an issue of the devolution of decision-making power over NRM.

In CFM, adaptive capacity is important because it emphasizes the ability of CFM to respond to social-ecological changes as a result of various internal and external threats to the exploitation and conservation of common resources. The performance of the common resource exploitation and conservation depends on the institutions and practices of communities. Thus, a collaborative approach is needed to improve adaptive management (Armitage, 2005).

2.5.2.3 Collective management of multi-actor processes

ComMod relies on theories of collective action, particularly regarding common resources and public goods. Of special interest is the linkage between game theory and creation of institutional settings favorable to sustainable NRM characterized by evolving (i) agreed-upon access rules and regulations defined by the resource users themselves, (ii) relations based on trust and social capital, and (iii) rules and regulations defined in relation to institutions at higher levels. This explains the emphasis given to the ComMod process on coordination and negotiation mechanisms among stakeholders seen as continual collective learning processes taking place in social networks in which solutions can emerge from interactions.

Adaptive co-management (combining the learning-by-doing approach of adaptive management with the participatory approach of collective management) refers to a flexible governance[1]-based approach to CFM tailored to specific places and situations (Armitage *et al.*, 2009; Schultz *et al.*, 2011). Institutions (both formal and informal rules and regulations) are important to regulate the interactions among stakeholders and between them and the SES in successful adaptive co-management. These rules and regulations can provide a framework used to mitigate environmental problems. Creating and adjusting the rules and regulations collectively lead to the confrontation of perceptions, interests and ideas, and the evolution of stakes and acceptable solutions. Based on adaptive management (learning from experiences) and collective management (sharing decision power among resource users and organizations), CFM choices and collective actions could be seen as hypotheses and experiments, respectively. The collective actions allow continuous adaptation through negotiated choices based on the monitoring of observed results. Consequently, this approach promotes a new kind of strong linkages between scientists, local resource managers (CFM committee members), and other land users (resource harvesters). Participatory modelling and simulation approaches are frequently used to facilitate adaptive co-management.

2.5.2.4 Constructivist epistemology[2]

ComMod tries to make explicit the different viewpoints and common representation of the SES constructed by diverse types of stakeholders based on their specific experiences and knowledge. Various stakeholders differently perceive a common NRM problem, and refer to different kind of knowledge (including cultural values) to analyze and interpret it. Stakeholders' actions depend on their perceptions on their SES environment, and these differently and partially contradictory perceptions are frequently at the origin of misunderstanding and at the root of conflicts. ComMod puts much emphasis on both individual and collective experiential or discovery learning mechanisms because social learning leads to a shared collective and distributed cognition among the diverse stakeholders allowing them to act on the current situation to improve it.

[1] **Governance** is defined as "the structures and processes by which people in societies make decisions and shape power" (Hill *et al*., 2012).

[2] **Epistemology** is "the branch of philosophy that examines the nature of knowledge, its presuppositions and foundations, and its extent and validate" ('Epistemology', 2011).

2.5.2.5 Post-normal science

ComMod practitioners adopt a posture which favours the improvement of the collective decision-making process (more than the characteristics of the decision itself) because of the high level of uncertainty related to the fact, social challenges, problem definition, etc. they deal with in the complex SES. Researchers in the field of post-normal science consider that soft social ecology[3] is based on the assumption that people construct their actual circumstances through learning along social processes. Hard sciences[4] can show that a SES is endangered but its sustainable land use finally depends on the outcomes of human interactions and agreement, learning, conflict resolution and collective actions. Consequently, the role of interdisciplinary teams including natural and social scientists is to understand and strengthen collective decision-making processes through the platforms of interactions. This also explains the importance given by ComMod to integrative processes engaging different stakeholders having diverse values, perceptions and interests, but who are all concerned by the problem at stake.

2.5.2.6 Patrimonial mediation

ComMod borrowed the importance of a prospective analysis of system evolution from the patrimonial[5] mediation approach, and it uses such exploration of possible future to facilitate the definition of long-term common goals by the stakeholders. Patrimonial mediation contributes to the understanding and practice of adaptive co-management. A patrimonial representation of an area or a set of common resources links past, present, and future generations of managers, focuses on the owner's obligations more than his/her rights, and promotes a common vision of sustainability that reconciles the needs and opinions of various stakeholders. Mediation is a negotiation approach which brings in a third and neutral party to facilitate agreement among different parties in conflict. It is an approach in which

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[3] **Soft scientists** look at social phenomena that cannot be reduced to their component parts or repeated outside of their complex settings (Douthwaite *et al*., 2001).

[4] Opposite to soft scientists, practitioners of **hard science** (e.g. most natural scientists and some social scientists) are trained to believe that the world they experience has an independent reality that they are discovering in their (repeatable and quantifiable) experiments (Douthwaite *et al*., 2001).

[5] **Patrimonial** is defined as "all the material and non-material elements that work together to maintain and develop the identity and autonomy of their holder in time and space through adaptation in a changing environment" (Ollagnon, 1989).

each party's viewpoints on the issue or the problem at stake are translated to others (Babin and Bertrand, 1998).

2.5.3 Main phases of a ComMod process

Based on Bousquet and Trébuil (2005a), there are three main phases of a ComMod process as follows:

(i) *Field investigations and literature search* to define initial key questions and to explicit hypotheses for modelling by raising a set of the questions to be examined by using the model.

(ii) *Modelling* to convert existing knowledge into a formal conceptual model to be implemented by simulation tool(s).

(iii) *Simulation tools* (either a RPG or a computer ABM) used to challenge the former understanding of the SES and to identify new key questions during participatory simulation sessions exploring possible future scenarios.

As a ComMod process is iterative and continuous, it can be repeated as many times as needed (Figure 2.3). In each loop of the ComMod process, several relevant and complementary field and laboratory activities are combined (e.g. individual in-depth interviews, ecological field investigations, focus group discussions, participatory modelling field workshop including gaming and simulation sessions). At the end of a single loop of the ComMod process, the conceptual model is revised, and the consistency of the hypotheses is reassessed.

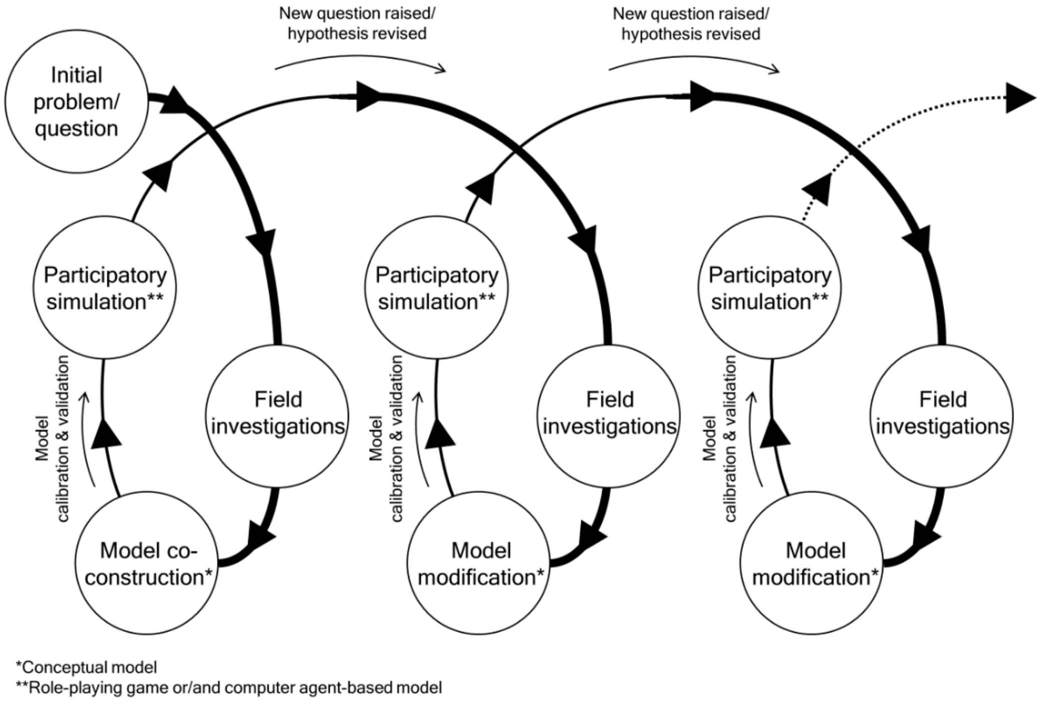


Figure 2.3: The iterative and continuous ComMod process (adapted from Barnaud *et al*., 2006).

2.5.4 Participatory modelling and simulation techniques and tools used in the ComMod approach

Several participatory modelling and simulation techniques and tools, including (i) Problem, Actors, Resources, Dynamics and Interactions (PARDI) method, (ii) Unified Modelling Language (UML) diagrams, (iii) Overview, Design concept and Details (ODD) protocol, (iv) RPG, and (v) computer ABM, are used in the ComMod process, as shown in Figure 2.4.

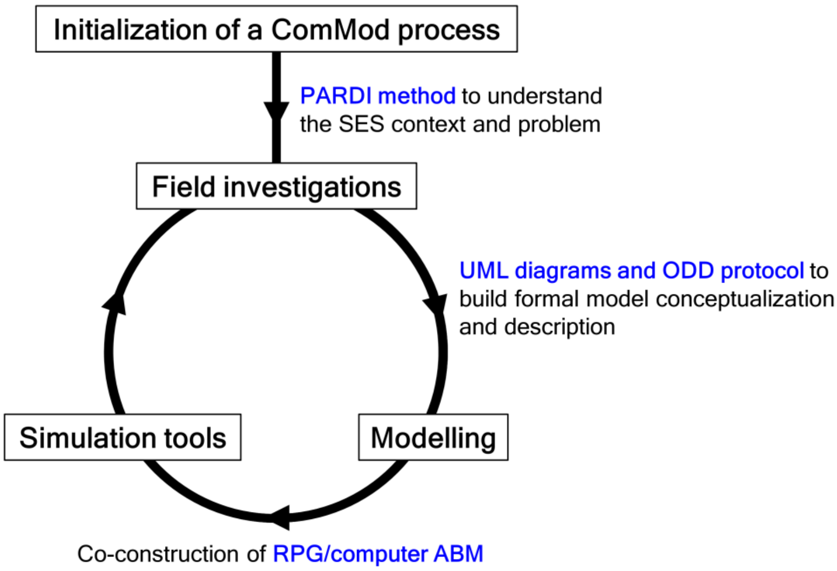


Figure 2.4: Participatory modelling and simulation techniques and tools, including PARDI (Problem, Actors, Resources, Dynamics and Interactions) method, UML (Unified Modelling Language) diagrams, ODD (Overview, Design concepts and Details) protocol, role-playing game (RPG), and computer agent-based model (ABM), used in each main phase of a ComMod process (adapted from Barreteau, 1998).

2.5.4.1 Formal model conceptualization and description

PARDI method

Originally, based on Étienne *et al.* (2011), ARDI is an acronym of the four following French words: acteurs, ressources, dynamiques, and interactions identifying the four steps used to elicit stakeholder mental models of a given SES they are acting on or living in. It allows the progressive emergence of a shared representation of the key components and dynamics of the SES and of the NRM problem to be examined by describing stakeholders, the resources, the processes, and the interactions among them. Later, the ARDI method was cited by several scholars as 'PARDI' (Le Coq *et al.*, 2013) where P (for problem) is a clear, concise, nonambiguous, and shared definition of the problem to be examined among the stakeholders in order to limit the level of complexity to be managed and to define a clear focus of the ComMod process.

The first step of the ComMod approach following the PARDI method focuses on collectively identifying a common problem. A group taking part in co-construction of the model must clearly address a key question, the formulation of which is adapted to the issue at stake.

The second step of the PARDI method is listing the key stakeholders and corresponding management entities, and the links between them. The practice proceeds in three stages. Initially, the group simply lists the principal stakeholders who they considered to be associated with the key question. Each actor proposed must be a direct stakeholder (a person who uses or whose practices have a direct impact on the key resources of the territory), or an indirect stakeholder (a person whose actions encourage direct stakeholders to change their practices). Next, the links among the identified stakeholders are specified, and these relationships are clarified in a simple way. Progressively, arrows are added to show the relationships. Lastly, always adhering to the principle of negotiation, the group must identify and clarify the management entities used by each direct stakeholder. Those can be spatially explicit entities (e.g. community forest microhabitat), or not (e.g. NTFPs, cash).

The third step is listing the relevant resources of the territory according to the key stakeholders previously identified, the term ‘resources’ exclusively applying to goods or products used by any stakeholders. The principal types of resources are often grouped within five main categories: infrastructure, water, minerals, plants, and animals. Each resource mentioned also needs to be identified its indicator which is relevant to making management decisions regarding a particular resource, and can be either quantitative or qualitative.

The subsequent step is listing the main processes driving changes in the territory in relation to the key question. These processes can deal with ecological dynamics (e.g. resource regeneration, ecological succession or vegetation transition), economic dynamics (e.g. evolution of farm gate prices of each resource), or social dynamics (e.g. indigenous knowledge transfer).

The last step consists of synthesizing answers to the three preceding questions by stressing the interactions between users and resources. This is a pivotal process in practices as it leads to a conceptual model representing all the interactions related to the key question. It is advisable to devote more time to this phase because it generally takes on half-day for a simple diagram (3–4 direct actors with 3–4 resources), and one day for a more complex diagram (5–8 direct actors with 5–10 resources). The group must then answer a following central question: How does each stakeholder use the resources and modify the processes?

All the diagrams resulting from the SES analysis based on the PARDI method can be translated into Unified Modelling Language (UML) diagrams to obtain a formal conceptual model.

UML diagrams

According to Müller and Bommel (2007), UML is a graphic representation developed and accepted as a standard by the Object Management Group (Booch *et al.*, 1997) to provide users with a ready-to-use and expressive visual modelling language to develop and exchange meaningful models, and to support specifications which are independent of particular programming languages and development process. Despite UML is commonly used as a language dedicated to software development, these statements provide a basis for its use for knowledge representation.

UML is composed of a number of diagrams among which:

- *Use case diagram* for requirement analysis,
- *Class diagram* for the concepts,
- *Object* diagram for the objects,
- *State-transition diagram* describing the behaviour of an object with state transitions,
- *Interaction diagram* describing how objects interact,
- *Activity diagram* describing detailed behaviour of an object or set of objects as a graph of actions or activities,
- *Realization diagram* to structure a software (a simulation model) into components,
- *Deployment diagram* to describe how a software (a simulation model) is distributed among a number of execution units (computers).

Not all these diagrams are useful for the purpose of modelling alone (not taking into account the programming phase), nor are all the details of each diagram necessary for doing so. That is we can classify these diagrams into three categories: (i) the diagrams specific to software engineering such as the use case, realization and deployment diagrams, (ii) the diagrams dedicated for modelling, providing complete specifications such as the class, state-transition and activity diagrams, and (iii) the diagrams dedicated to illustrate particular cases of structures or interactions such as the object and interaction diagrams. Despite the interest of the latter diagrams for graphically representing scenarios and actual instances or cases through a simulation model, only three of the most common ones (class, state-transition and activity diagrams) were used in this study.

ODD protocol

Although the UML diagrams are very helpful to conceptualize a simulation model, there is still a need for describing such a simulation model which can make it easy to understand and to duplicate. For this reason, Grimm *et al.* (2006) and Grimm *et al.* (2010) proposed a standard protocol called ODD. It is composed of three blocks (overview, design concepts, and details as a mnemonic 'ODD') and seven elements, as shown in Table 2.3. The 'overview' provides an overview of the overall purpose and structure of the model. Readers very quickly can get an idea of the model's focus, resolution, and complexity. The block or element 'design concepts' does not describe the model itself, but rather than describes the general concepts underlying the design of the model. The 'details' present the details that were omitted in the overview. All information required to completely re-implement the model and run the baseline simulations can be provided here.

Table 2.3: Seven elements of the ODD protocol and their description grouped into three blocks: overview, design concepts, and details (Grimm *et al*., 2006; 2010).

Block	Element and its description
1. Overview	*1.1 Purpose:* the clear, concise and specific purpose of a simulation model has to be stated first because without knowing it, readers cannot understand why some aspects of reality are included while others are ignored. This element informs about why we need to build a complex model, and what, in general and in particular, we are going to do with our model. *1.2 Entities, state variables, and scales:* an entity is a distinct or separate object or actor that behaves as a unit and may interact with other entities or be affected by external environmental factors. Its current state is characterized by its state variables or attributes. A state variable or attribute is a variable which distinguishes an entity from other entities of the same type or category, or traces how the entity changes over time. Most simulation models, specifically to INRM, include the following types of entities: agents/individuals, spatial units, environment, and collectives. In describing spatial and temporal scales and extents (the amount of space and time represented in a simulation), it is also important to specify what the model's units represent in reality. *1.3 Process overview and scheduling:* to understand a simulation model, we must know which environmental and individual processes are built into the model. At this stage, a verbal and conceptual description of each process and its effect is sufficient as this element aims to give a concise overview. In addition, the scheduling of the model processes is described. This deals with the order of the processes and the order in which the state variables are updated.
2. Design concepts	*2.1 Design concepts:* provide a common framework for designing and communicating a simulation model.
3. Details	*3.1 Initialization:* simulation model results cannot be accurately replicated unless the initial conditions are known. This element deals with such questions as: What is the initial state of the model world, i.e. at time $t = 0$ of a simulation run? In details, how many entities of what type are there initially, and what are the exact values of their state variables (or how were they set stochastically)? Is initialization always the same, or is it allowed to vary among simulations? Are the initial values chosen arbitrarily or based on data?

Table 2.3 (cont’).

Block	Element and its description
3. Details (cont’)	*3.2 Input data:* the dynamics of many simulation models are driven by some environmental variables (sometimes called external forcings) as ‘input’ of a simulation model which change over space and time. ‘Driven’ means that one or more state variables or processes are affected by how these environmental variables change over time, but these environmental variables are not themselves affected by the internal variables of the model. Alternatively, external models can be used to generate input. Obviously, to replicate a simulation model, any such input has to be specified and the data or models provided, if possible. If a model does not use external data, this element should nevertheless be included. Note that ‘input data’ does not refer to parameter values or initial values of state variables. *3.3 Sub-models:* all sub-models representing the processes listed above in the element ‘process overview and scheduling’ are presented and explained in details. If parameterization is not discussed outside the ODD description, it can be included here.

2.5.4.2 Role-playing game (RPG)

One of the earliest definitions of a role-playing game (RPG) was given by Lortz (1979) as “any game which allows a number of players to assume the roles of imaginary characters and operate with some degree of freedom in an imaginary environment”. A RPG is more collective and social than competitive, has no time limits, is not scored, and has no definitions of winning or losing (Waskul and Lust, 2004; Dung *et al.*, 2009). It is composed of six features as follows: (i) game world, (ii) participants, (iii) characters, (iv) game master, (v) interaction, and (vi) narrative, and has several forms, e.g. pen-and-pencil/table-top, live-action, single player digital, massively multi-player online (Hitchens and Drachen, 2009).

When a RPG is used in INRM, the concept of multi-agent system (MAS), a metaphor of the social and biophysical dimensions of reality that consider a SES as a set of interacting autonomous entities located within a given environment (Drogoul and Ferber, 1994), is usually applied for building such a RPG (Étienne, 2003; Bousquet and Trébuil, 2005b). Following the ComMod approach relying on the concept of MAS, a RPG is a gaming and simulation tool, an implementation of a conceptual model, used to (i) understand and enrich (or simplify) the model, and more precisely to perceive the differences between the model and actual circumstances, (ii) validate the model (both individual behaviours and properties of a SES), or to propose modifications, and (iii) propose desirable scenarios to be assessed (Bousquet and Trébuil, 2005b). In other words, it is used for better understanding and representing a complex SES among heterogeneous stakeholders and interactions among individual behaviour contributing to the SES dynamics. It is also mobilized to facilitate exchanges and collective learning leading to an improved adaptive capacity among the participating stakeholders. However, the use of a RPG is costly and time consuming (Promburom and Bousquet, 2008).

2.5.4.3 Computer agent-based model (ABM)

A computer agent-based model (ABM) represents a set of interacting (often heterogeneous) agents who implement their tasks in a common environment based on their specific objectives and available resources (Bousquet and Le Page, 2004; Gleizes *et al.*, 2011). It is often used in association with a RPG to deal with the above-mentioned limitations of the RPG in a ComMod process.

In recent years, computer ABMs have become popular in several fields, particularly in ecology and common-pool resource management, especially to build a shared and understandable representation of complex SESs managed by local actors. The computer ABM can also be used to run, more or less participatory, simulations in order to identify, evaluate, and discuss the outcomes of possible resource management scenarios proposed by the researchers or the concerned stakeholders (Étienne *et al.*, 2003; Bah *et al.*, 2006).

The application of a computer ABM has been used in community common-pool resource management to deal with various kinds of resources, such as water (Wise and Crooks, 2012) and fisheries (Berman *et al.*, 2004). However, its application to forest resources has been limited so far (Purnomo and Guizol, 2006; Campo *et al.*, 2009), especially to facilitate knowledge exchange among stakeholders and to promote the collective design of a community forest management (CFM) action plan. Furthermore, using a computer ABM to simulate a SES across institutional scales, such as scaling-up a CFM from the village level to a higher administrative scale, is still a challenging task (Lippe *et al.*, 2019).

CHAPTER III
METHODOLOGY

3.1 Ecological field studies based on the five main categories of community forest ecosystem functions

3.1.1 Carrier functions

The secondary data based on Nantasen *et al.* (2005) and Anonymous (2009) were used to analyze the trend of the community forest area changes since the official establishment of the community forests in 1976 until 2009.

3.1.2 Information functions

Field surveys were conducted through individual in-depth interviews by using a semi-structured guideline. The organization of the guideline covered the following three topics:

(i) history and evolution of the community forests,

(ii) CFM rules and regulations, and current CFM problems, and

(iii) non-timber forest products (NTFPs) found in the community forests, and their occurrence period and farm gate price.

The specific questions of the semi-structured guideline are provided in Appendix 1.

To complete the study of NTFPs found in the community forests and their farm gate price from the individual in-depth interviews, a focus group discussion was also performed with local key informants who frequently harvest NTFPs in the community forests.

3.1.3 Habitat functions

3.1.3.1 Tree species composition

Field investigations were conducted with local key informants by using the plot sampling technique. There were three sampling plots of 40 × 40 m^2 in the community forests of villages 1 to 3. Due to the geographical characteristics of hilly land with steep cliffs and the small community forest size, there were two sampling plots for villages 4 to 6 and only one sampling plot for village 7. All of the trees (classified by at least 4.5 cm of their diameter at breast height, DBH) in each sampling plot were recorded with their vernacular name (given by the local key informants) and on photographs to identify their scientific name by using a pictorial key (Gardner *et al.*, 2007). The Shannon-Wiener's species diversity index (H′) was calculated by the following equation (Gurevitch *et al.*, 2006):

$$H' = -\sum_{i=1}^{s} (p_i \ln p_i) \text{..........[Equation 1]};$$

s is the number of species, and p_i is the proportion of species i in the community.

The top three dominant species were identified based on the important value index (IVI) calculated as follows (Odum and Barrett, 2005; Gurevitch *et al.*, 2006):

$$\text{Relative density of a species (\%)} = \frac{\text{the number of individuals of a species} \times 100}{\text{the total number of individuals of all species}}$$

$$\text{Frequency of a species (\%)} = \frac{\text{the number of samples in which a species occurs} \times 100}{\text{the total number of samples}}$$

$$\text{Relative frequency of a species (\%)} = \frac{\text{Frequency of a species} \times 100}{\text{Summation of the frequencies of all species}}$$

$$\text{Relative dominance of a species (\%)} = \frac{\text{Total biomass of a species} \times 100}{\text{Total biomass of all species}}$$

$$\text{IVI (\%)} = \frac{\text{relative density + relative frequency + relative dominance}}{3} \text{..........[Equation 2].}$$

Sørensen-Dice's similarity index was calculated by the following equation (Gurevitch *et al.*, 2006):

$$\text{Sørensen-Dice's similarity index} = \frac{2a}{2a + b + c} \text{..........[Equation 3]};$$

a is the number of species in samples A and B (joint occurrence),

b is the number of species in sample B, but not in sample A, and

c is the number of species in sample A, but not in sample B.

3.1.3.2 Richness of soil fauna

Field investigations were conducted twice (once in wet season and another in dry season) in NTFP harvesting areas of the community forests (defined as areas actually used to gather NTFPs by local villagers) based on the plot sampling technique. Soil fauna can be divided into three major groups based on their size: macro- (larger than 2 mm), meso- (average size of 0.2–2 mm), and micro-soil fauna (less than 0.2 mm) (Lavelle, 1997). However, this study only focused on macro- and meso-soil fauna. In each village, three sampling plots of 1×1 m^2 were used for collecting macro-soil fauna. Macro-soil fauna were collected and preserved by 70% ethanol. In each sampling plot of 1×1 m^2, there was a sub-sampling plots of 20×20 cm^2 for collecting meso-soil fauna. Soil samples (at the depth of 0–5 cm) were collected for separating meso-soil fauna (preserved by 70% ethanol) in the laboratory by using Tüllgren funnel. Macro- and meso-soil fauna were identified under stereomicroscope by using identification key (McGavin, 2002). The Shannon-Wiener's index of species diversity (H′) and the Sørensen-Dice's similarity index were calculated by the equations 1 and 3, respectively.

3.1.3.3 Species richness of wild mushrooms

Field investigations were conducted with local key informants once a month in the rainy and cool-and-dry seasons (from June 2015 to February 2016) by using the grid-based sampling technique. The NTFP harvesting areas in all community forests were divided into grids of 100×100 m^2. Mushrooms were collected in the field, and their scientific names were identified by using pictorial keys (Royal Society, 2007; Chandrasrikul *et al.*, 2008; Sanoamuang, 2010) before being checked by specialists from the Department of Botany at the Faculty of Science, Chulalongkorn University. The Shannon-Wiener's index of species diversity (H′) and the Sørensen-Dice's similarity index were calculated by the equations 1 and 3, respectively.

3.1.4 Regulation functions

3.1.4.1 Soil chemical characteristics

Field investigations were conducted in NTFP harvesting areas of the community forests. Each community forest, three random soil samples were collected by a screw auger at the depth of 0–20 cm. All soil samples were sent to the Soil Analysis Laboratory at Faculty of Environment, Kasetsart University, Bangkok, Thailand to analyze soil chemical characteristics with determination of soil types based on a national classification as follows:

(i) soil reaction (soil pH) by using pH meter,
(ii) organic matter (%) by Walkley-Black Titration method,
(iii) total Nitrogen (%) by Kjeldahl method,
(iv) available Phosphorus (ppm) by Bray II method, and
(v) available Potassium (ppm) by 1N Ammonium Acetate method.

Soil chemical fertility was interpreted based on the soil characteristics, as the criteria shown in Appendix 2.

3.1.4.2 Carbon storage in aboveground biomass

All of the trees from section 3.1.3.1 (tree species composition) were recorded with their DBH and height (H). The tree aboveground biomass (AGB) was calculated by the allometric equations of (Ogawa *et al.*, 1965), specifically used for estimating the tree aboveground biomass in mixed deciduous and dry dipterocarp forests of Thailand (Viriyabuncha, 2003), as follows:

$$\text{Stem biomass (Ws)} = 0.0396\,(D^2H)^{0.9326} \quad \text{kg}$$

$$\text{Branch biomass (Wb)} = 0.003487\,(D^2H)^{1.027} \quad \text{kg}$$

$$\text{Leaf biomass (Wl)} = \frac{1}{\frac{28}{Ws+Wb} + 0.025} \quad \text{kg}$$

$$\text{AGB} = Ws + Wb + Wl \quad \text{kg;}$$

D is tree stem diameter at breast height (cm), and H is tree height (m).

The carbon storage in the aboveground biomass was estimated at approximately 50% of the tree biomass (Brown and Lugo, 1982).

3.1.5 Production functions

Field investigations were conducted once a month for 12 months (from June 2015 to May 2016) using the grid-based sampling technique. The grids 100 × 100 m^2 from section 3.1.3.3 (species richness of wild mushrooms) were used for the field studies of production functions. Sample of *Melientha suavis*, queen brood of *Oecophylla smaragdina*, and edible mushrooms (identified by the local key informants from section 3.1.3.3) were collected. The physical productivity and annual production of each kind of NTFPs were calculated according to their total fresh weight in all harvesting locations.

The data on diversity and typology of NTFP harvesters and of their practices and related decision-making processes were collected through individual in-depth interviews by using a semi-structured guideline, as provided in Appendix 1.

3.2 Participatory assessment of community forest ecosystem functions

3.2.1 Design and development of a participatory assessment tool

As mentioned early, among diverse ecosystem assessment tools, RAWES and TESSA have strengths to be used in a participatory way with local people since they require low specialist technical knowledge and computational skills. Consequently, RAWES and TESSA were selected as reference methods to develop a new tool for the participatory assessment of community forest ecosystem functions.

Fourteen key community forest ecosystem functions covering all the five main categories and their indicators were selected based on De Groot *et al*. (2002) and De Groot (2006), as shown in Table 3.1.

Table 3.1: Selected ecosystem functions and their indicator(s) for developing a participatory assessment tool.

	Ecosystem functions	Indicator(s)
1. Regulation	1.1 Gas regulation	Effectiveness to mitigate global warming through carbon sequestration in aboveground biomass*
	1.2 Water supply	Occurrence of water resources in the forest and its ability of catchment throughout a year
	1.3 Soil formation and nutrient regulation	Amount of litter and frequency to find cross wood debris (CWD) and fallen branches*
2. Habitat	2.1 Refugee and nursery	Species richness of wildlife Forest patch shape*, ** Forest structure*, ***
3. Production	3.1 Food	Number of edible NTFP species
	3.2 Raw materials	Number of tree species
	3.3 Medicinal resources	Number of medicinal plant species
4. Information	4.1 Aesthetic information	Number of locations in the forests with attractive landscape sceneries****
	4.2 Research and education	Occurrence of (unofficial) nature trails and the number of research projects during 2013–2017
	4.3 Cultural creation	CFM rules and regulations and their enforcement
5. Carrier	5.1 Habitation	Occurrence of a dhamma retreat in/nearby the forest*
	5.2 Transportation	Occurrence of small pathways across the forest to agricultural areas
	5.3 Tourism-facilities	Creation of ecotourism (the future opportunity)****
	5.4 Reforestation	Possible changes of the forest areas in the next 5–10 years****

*Indirect indicator

**According to the modern biogeographic theory, the optimal shape of a forest area is supposed to be circular to minimize dispersal distances within the area. While dispersal rates to outlying parts of an elongated or peninsular forest area from more central parts may be sufficiently low (Margules *et al.*, 1982).

***Theoretically, more permanent communities are developed at a mature or climax stage (identified by high proportion of large forest tree) compared with the early stages of ecological succession (Odum and Barrett, 2005).

****Assessed through a collective agreement on the local evaluators' opinions.

A procedure for calculating the 'status score' of each community forest is displayed in Figure 3.1. Each selected community forest ecosystem function was scored by using the scoring criteria shown in Appendix 3. A total score of each main group of community forest ecosystem function was calculated by summation of all the raw scores in the same category. As mentioned before, an ecosystem can function as usual when its all five main ecosystem functions work together systematically (Figure 2.1). Therefore, the total score of each main category of community forest ecosystem functions were equally calibrated into 100 points. Summation of the calibrated total scores in all five main community forest ecosystem functions was considered as the 'status score' of each community forest.

Summation → Calibration → Summation

	Selected ecosystem functions	Raw score	Total score	Calibrated total score	Status score
1. Regulation	1.1 Gas regulation	10	30	100	500
	1.2 Water supply	10			
	1.3 Soil formation and nutrient regulation	10			
2. Habitat	2.1 Refugee and nursery		30	100	
	2.1.1 Species richness of wildlife	10			
	2.1.2 Forest boundary shape	10			
	2.1.3 Forest structure	10			
3. Production	3.1 Foods	10	30	100	
	3.2 Raw materials	10			
	3.3 Medicinal resources	10			
4. Information	4.1 Aesthetic information	10	30	100	
	4.2 Research and education	10			
	4.3 Cultural creation	10			
5. Carrier	5.1 Habitation	10	40	100	
	5.2 Transportation	10			
	5.3 Tourism-facilities	10			
	5.4 Reforestation	10			

NB: All the scores shown in this figure are the possible maximum score.

Figure 3.1: Calculating procedure of the participatory assessment of community forest ecosystem functions.

The five-point Likert scale was used as a scaling prototype in this study as it is one of the most fundamental and frequently used scales in several research fields (Joshi *et al.*, 2015). Therefore, the community forest ecosystem status was classified into five scales including very good, good, moderate, poor, and very poor, as shown in Table 3.2.

Table 3.2: The criteria for classifying the status of each main community forest ecosystem function based on the calibrated total score and the status of community forest ecosystem based on the status score.

Status	Calibrated total score in each main ecosystem function (100 points in maximum)	Status score (500 points in maximum)
Very good	≥ 81	≥ 401
Good	61–80	301–400
Moderate	41–60	201–300
Poor	21–40	101–200
Very poor	≤ 20	≤ 100

3.2.2 Testing of the participatory assessment tool

The tool was tested to assess urban ecosystems in and nearby Chulalongkorn University, Bangkok, Thailand, such as the Chulalongkorn University Centenary Park. Before starting the actual assessment of ecosystem functions in the field, the tool was tested with local evaluators at the conserved forest area of the Plant Genetic Conservation Project under the Royal Initiative of HRH Princess Maha Chakri Sirindhorn located nearby the community forests of village 2 (Figure 3.2).

Figure 3.2: Testing of the participatory assessment tool with local evaluators at the conserved forest area nearby the community forests of village 2.

3.2.3 Use of the participatory assessment tool in the field

The tool was then used in field investigations with local evaluators to assess the ecosystem status at all seven community forests based on the line-transect sampling technique (Figure 3.3). In each village, a line-transect of 200 m was jointly selected by all the local evaluators. Two line-transects were chosen in each village for villages 2 and 3 due to their large community forest area. The data of these following ecosystem functions were gathered in each line transect: gas regulation, water supply, soil formation and nutrient regulation, refugee and nursery (forest structure), raw materials, medicinal resources, aesthetic information, habitation, and transportation.

After the field data collection, a focus group discussion was conducted to gather the data of remaining ecosystem functions which could not be recorded in the field as follows: refugee and nursery (species richness of wildlife, and forest patch shape), food, research and education, cultural creation, tourism-facilities, and reforestation. Community forest degradation risks were also collectively defined and evaluated during the focus group discussion.

After completion of the field investigations, a plenary debriefing were conducted through a one-day-field workshop in order to share the results from the field investigations and the knowledge on how to interpret the data with the local evaluators.

Figure 3.3: Field investigation with local evaluators based on the line-transect sampling technique.

3.3 Participatory modelling and simulation process

3.3.1 The first participatory modelling and simulation sequence

3.3.1.1 Model design

The complex SES of the community forests was first analyzed and simplified by using the PARDI method, an updated version of the original ARDI method proposed by Étienne *et al.* (2011) to collaboratively construct conceptual models with stakeholders. This method was also used by the researchers to build their own representation of its functioning based on their understanding of its characteristics and current management. A clear and concise key question to be examined in a ComMod process was specified. A simplified system (including its principal components, and their dynamics and interactions linked to the key question) was represented into a formal conceptual model by building a UML class diagram (Booch *et al*., 1997), and was also described based on the ODD protocol (Grimm *et al*., 2006; 2010).

3.3.1.2 Construction of an initial RPG

The first version of the conceptual model was implemented as an initial RPG. An abstract landscape was conceived as a gaming board with a spatial grid of 25 cells. The players of this initial RPG were the local representatives from both the seven villages and the Subdistrict Administrative Organization (SAO). The three common NTFPs including *Melientha suavis*, queen brood of *Oecophylla smaragdina*, and edible mushrooms were represented by beads in green, orange, and yellow colours, respectively. The RPG was tested with a small group of graduate students at Faculty of Science of Chulalongkorn University before being used with local stakeholders in a field workshop.

3.3.1.3 The first participatory gaming field workshop

A two-day participatory gaming field workshop was organized to introduce and make use of the RPG with heterogeneous local stakeholders, including local villagers and their leaders (e.g. village headmen), local CFM committee members, and staff members from the SAO (Figure 3.4). Most local villagers avoid sharing their ideas or to argue/discuss with others when they have to be with their leaders. The participants were therefore separated into two groups depending on their role in CFM to participate in the workshop on different days. The first group was made of local villagers with no administrative role in CFM. They were selected by their leaders to participate in the workshop on the first day based on their actual practices of harvesting NTFPs in the community forests. Another group was made of village headmen, CFM committee members, and SAO staff members who were invited by the researchers to join the workshop on the second day.

Figure 3.4: The first participatory field workshop organized and implemented based on the initial role-playing game (RPG).

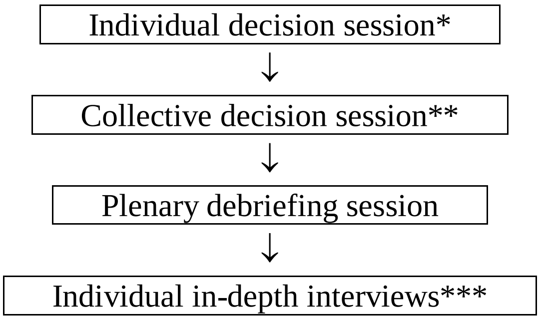
The scheduling of the workshop on both days was similar with the two different participatory gaming sessions, as shown in Figure 3.5. After completing the second session, a debriefing was conducted to discuss the following topics:

(i) comparison of the ecological (the average cumulated harvested resources per player) and economic (the average cumulated income per player) performances achieved between the two participatory gaming sessions,

(ii) analysis of the similarities and differences between the RPG and reality, in relation to the roles played in the RPG to actual behaviour in the field, and

(iii) resource dynamics influenced by the amount of annual rainfall and decision-making on resource harvesting influenced by the different economic situations.

Individual in-depth interviews were conducted after the workshop by using a semi-structured guideline, as shown in Appendix 4.



*Individual decisions were allowed in the first session of both the first and second workshops to make the participants familiar with the tool and its components, and decision rules.

**Collective decisions were allowed in the second session of the first workshop, but in both the second and third sessions of the second workshop to facilitate the exchange of knowledge and experiences among the participants.

***Two days after each workshop, individual in-depth interviews were performed by using a semi-structured guideline to evaluate the effects of the model use on the local stakeholders.

Figure 3.5: Scheduling of a participatory gaming and simulation field workshop.

3.3.2 The second participatory modelling and simulation sequence

3.3.2.1 Model co-design and construction

The second version of the conceptual model, taking into account the feedback received from the local stakeholders in the first participatory gaming field workshop, was also represented formally as a new UML class diagram (Booch *et al*., 1997), and described based on the ODD protocol (Grimm *et al*., 2006; 2010).

This new version of the model was implemented as a computer-assisted role-playing game (cRPG) by using the CORMAS (COmmon-pool Resource and MAS) modelling and simulation platform, which is dedicated to natural and common-pool resource management and uses the Smalltalk object-oriented computer language (Bousquet *et al.*, 1998; Bommel *et al.*, 2016). Several tests and corrections were conducted in the laboratory to verify that the model behaved logically and realistically. The model was verified to ensure its coherence with the conceptual model. All the parameters in the model were also calibrated based on data obtained from the previous preliminary field studies. After completion of the model verification and calibration in the laboratory, it was submitted to the local stakeholders for their collective validation during the second field workshop.

3.3.2.2 The second participatory gaming and simulation field workshop

A new one-day-field workshop was held at the study site to use the modified model implemented as a cRPG with 21 heterogeneous stakeholders (Figure 3.6). Twelve of them were village leaders, involved in the CFM of their own village, and SAO staff members. They were invited to participate in this workshop because they took part in the co-design of the model during the previous phase. The research team gave an opportunity to these 12 local stakeholders to invite other nine participants playing a role in CFM of their villages to join the workshop.

Figure 3.6: The second participatory field workshop organized with heterogeneous stakeholders and used the CoComForest model implemented as a computer-assisted role-playing game (cRPG).

Beyond the validation of the modified model by the participants, another objective of the workshop was to facilitate the exchange of knowledge, perceptions and experiences about CFM and NTFP harvesting among the participants, including the research team. The scheduling of the workshop, shown in Figure 3.5, included three successive participatory gaming and simulation sessions. A short debriefing session was held at the end of the first session to validate, or reject and change, the features of the simulation tool. This is because it is essential to ensure that the model is acceptable to the stakeholders, and is making sense for them to be eager to use it as a tool for sharing points of view and simulating possible future scenarios (Trébuil *et* *al.*, 2005). Based on the propositions made by the local participants, two subsequent sessions explored scenarios introducing the establishment of firebreaks in the landscape and the intrusion of outsiders intensively harvesting NTFPs. Scenario simulations were used with the objectives of stimulating exchanges and making progress towards collective decisions and an agreement on an action plan to improve local CFM.

At the end of the workshop, the participants discussed the following two topics during a plenary debriefing. Firstly, they compared the results of the three gaming and simulation sessions, based on the total amount of resource units harvested by each player and the overall remaining resource units in the landscape at the end of each session. Secondly, they discussed the similarities and differences between these results and their actual field circumstances, especially the relationships between the roles played in the gaming and simulation sessions and the actual behaviour of the local actors. Two days after the event, individual in-depth interviews were performed with the workshop participants by using a semi-structured guideline provided in Appendix 5.

CHAPTER IV
ECOSYSTEM FUNCTIONS OF THE LAINAN’S COMMUNITY FORESTS

4.1 Carrier functions: changes of the community forest areas during 1976–2009

The community forest attributes of each village are shown in Table 4.1. Based on the maximum elevation, the Lainan’s community forests were relatively classified into lower (≤ 280 above mean sea level [amsl]), middle (> 280, but ≤ 300 m amsl), and upper (> 300 amsl) ones.

(iii) According to the current total area, the largest community forests with 192 ha belonged to village 3 while the community forest of village 6 was the smallest one with only 3 ha. However, when comparing the total areas investigated in 2009 and during 1976–1995, the resulted showed that during the last few decades, the total area of the community forests in all the seven villages of Lainan Subdistrict decreased by at least 70%. This suggested that the Lainan’s community forests have been vulnerable due to deforestation.

Table 4.1: Profile of the study site at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Characteristics	**Village**						
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**
Community forest attribute							
Geographical location (UTM zone 47Q)	688010 E	689740 E	691830 E	696210 E	701530 E	702840 E	699860 E
	2056010 N	2054170 N	2055850 N	2056120 N	2054100 N	2053750 N	2054460 N
Topographical situation	Lower	Lower	Middle	Upper	Upper	Upper	Upper
Maximum elevation (m amsl)	280	265	300	330	305	310	320
Total area (1976–1995) (ha)	800	1,040	640	160	560	400	480
Total area (2009) (ha)	45	134	192	19	31	3	7
Decline in total area (%)	94	87	70	88	94	99	99
Community forest rules and regulations							
Fine for logging (THB/tree)	5,000	5,000	10,000	1,000	10,000	1,000	1,500
Fine for wildlife hunting (THB/animal)	5,000	n/a	5,000	n/a	n/a	n/a	n/a
Fine for dumping waste in the forest (THB)	10,000	10,000	2,500	500	n/a	n/a	n/a
Fine for burning (THB)	n/a	10,000	5,000	n/a	n/a	500	n/a
Buddhist religious protection ritual	Yes	No	Yes	No	No	No	No
Harvesting pressure							
Total number of households (HHs)	273	254	149	238	145	47	48
Number of harvesting HHs	184	175	149	25	25	30	48
Estimated number of harvesters	234	225	249	25	25	35	53

Source: Author's own survey and adapted from Nantasen *et al.* (2005) and Anonymous (2009).

4.2 Information functions

4.2.1 History and evolution of the local community forestry

Based on Nantasen *et al*. (2005), Lainan's community forests have officially been operating for more than 40 y and the evolution of community forestry in this area can be interpreted based on a sequence of three main periods:

(i) *Forest conservation activities (1968–1975).* Forests were conserved for the main purposes of protecting the remaining forest areas from deforestation due to the government policy on logging concessions issued in 1963 and cattle grazing.

(ii) *Official establishment of community forests (1976–1995).* Community forests in all villages of this subdistrict were officially established and their boundaries delineated. Commanding rules and regulations for logging prohibition were introduced, and local management committees were set up.

(iii) *Forest rehabilitation (since 1996).* Because deforestation still occurred during the previous two periods, logging in community forests is being strictly prohibited in every village. However, the close collaboration of local villagers in CFM and conservation is still limited as most of the villagers consider that CFM is mainly a duty of the village headmen and local CFM committees.

4.2.2 Local rules and regulations for CFM

Each village had its own CFM rules and regulations, as shown in Table 4.1. Logging was strictly prohibited in all community forests. Some villages, particularly the lower ones, prohibited wildlife hunting, waste dumping, and forest burning. Lower villages also had Buddhist protection rituals as a part of their conservation culture combining religious and spiritual beliefs. The SAO played a role to support CFM by providing information and promoting collaboration in CFM among village headmen, CFM committee members, and local villagers. The SAO also allocated budgets for CFM activities, especially for the establishment of firebreaks and reforestation.

4.2.3 NTFPs found in the community forests

There were at least 183 different NTFPs including 65 plants/algae, 85 animals, and 33 edible mushrooms, as shown in Table 4.2. The list of all 183 NTFPs and their farm gate price is presented in Appendix 6. Although some of them had high farm gate price (higher than 150 THB/kg); their availability was very low, such as *Carebara* sp. (แมลงมัน), queen brood of *Crematogaster* spp. (ไข่มดสี่). Local people told that *Carebara* sp. can be found only once a year during early wet season (late May to early June), and *Crematogaster* spp. has been rarely found in the community forests during the last decade. Aquatic animals (mollusks, crustaceans, fishes, and amphibians) were only found in the village 3 because there was no water resource which can store water throughout a year in the community forests of other villages. Reptiles, avian, and mammals could be hunted outside the community forests, such as in agricultural areas, or in the villages due to the CFM rules and regulations which wildlife hunting is prohibited in the community forests (Table 4.1).

Table 4.2: The number of NTFP species found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand based on focus group discussion and individual in-depth interviews.

	Type of NTFPs	Number of NTFPs species	
1. Plant/Algae		65	
2. Animal	2.1 Earthworm	1	85
	2.2 Mollusk	6	
	2.3 Crustacean	4	
	2.4 Insect/Arachnid	13	
	2.5 Fish	8	
	2.6 Amphibian	7	
	2.7 Reptile	9	
	2.8 Avian	21	
	2.9 Mammal	16	
3. Edible mushroom		33	
Total		**183**	

Based on high farm gate price (≥ 150 THB/unit) and availability of the NTFPs, and the CFM rules and regulations, the following three NTFPs: *M. suavis*, queen brood of *O. smaragdina*, and edible mushrooms were specified as the major NTFPs found in Lainan's community forests.

M. suavis is a deciduous tree belonging to the Opiliaceae family and is commonly found in the mixed deciduous and dry dipterocarp forests of Thailand (Prathepha, 2000; Julapak *et al.*, 2016). It has a simple, alternate, and shiny leaf with an oval to round shape. The flowers are dioecious and assembled in panicles (Charoenchai *et al.*, 2013). During the dry season, from February to May, edible young shoots and young and/or blooming flowers are gathered by local people (Prathepha, 2000) (Figure 4.1).

Figure 4.1: Individual tree of *Melientha suavis* in a community forest; small photo: harvested young shoots.

O. smaragdina (weaver ant) is one of the most favoured edible insects in many countries of Southeast Asia. It is an arboreal ant building nests by binding living leaves together and fixing them with silk produced by its larvae. Its colonies are polydomous and consist of multiple nests (Sribandit *et al.*, 2008; Van Itterbeeck *et al.*, 2014). Queen broods of *O. smaragdina*, which refer to larvae and pupae destined to become new queens as well as their last stage as imago virgin queens, have been gathered as a source of food for centuries (Offenberg and Wiwatwitaya, 2010) (Figure 4.2).

Figure 4.2: Traditional harvesting practice for *Oecophylla smaragdina*; small photo: queen broods. A long (around 7 m) bamboo stick with a net (usually a maize bag) mounted close to the pointed tip is used to pierce the *Oecophylla smaragdina* nests. When the bamboo stick is shaken, the queen brood and mature ants (mostly worker ants) are dropped into the net. Fine starch powder is used to prevent the worker ants from taking the brood out of the net. Only the broods are then collected in a container (usually a homemade basket used for sticky rice) (adapted from Sribandit *et al*., 2008).

Wild edible mushrooms have long been traditionally harvested from forests worldwide because they are difficult to domesticate and cultivate (Zhang *et al.*, 2014). In Thailand, several edible mushroom species, such as *Astraeus hygrometricus*, *Morchella conica*, *Phlebopus portentosus*, and *Pleurotus giganteus*, are gathered by rural people for household consumption. Because of the high market price of some species, they also provide a complementary income for resource-poor households (Mortimer *et al.*, 2012) (Figure 4.3).

Figure 4.3: Edible mushrooms at a local market: (a) After completing harvest of edible mushrooms in the community forests, local harvesters sorted these mushrooms according to their farm gate price. High priced mushrooms (higher than 150 THB/kg), such as *Astraeus* sp., *Lentinus polychrous*, and *Russula virescens*, were sold separately; while low priced mushrooms were sold in mixtures. (b) Mixture of low priced edible mushrooms.

Each of these three principle types of NTFPs had different occurrence periods, as shown in Figure 4.4. The occurrence period was defined as the period in which NTFPs provide their edible parts (*M. suavis* and edible mushrooms) or reach the edible stage (*O. smaragdina*). *M. suavis* produced its new buds and leaves in the warm and dry season, while *O. smaragdina* produced its queen broods from the end of the cool and dry season in January until the end of the warm and dry season in May. Most of the edible mushrooms developed their fruiting body in the wet season from June to September. However, several species, such as *Russula virescens*, were found from the late wet season in October to the early cool and dry season. The very small production of *Lentinus polychrous* occurred in the cool and dry season, from October to December.

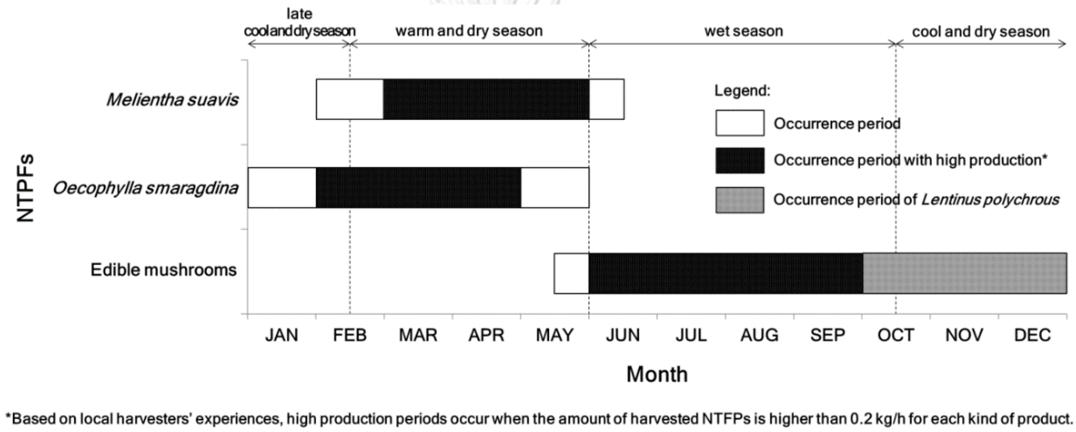


Figure 4.4: Occurrence periods of the three major NTFPs based on the local harvesters' experiences at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

4.3 Habitat functions

4.3.1 Tree species composition

4.3.1.1 Tree species composition among the villages

Among the seven villages, the tree species composition of each community forest is shown in Table 4.3. Villages 1 and 2 had the highest number of tree species (36 species). Although village 7 had the lowest tree density (850 trees/ha) and low number of tree species (24 species), it had the highest value of tree species diversity index (1.10). While village 6 had the lowest number of tree species (20 species) and the lowest value of tree species diversity index (0.67).

Table 4.3: Tree species composition of each community forest at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Village	Number of individuals	Density (trees/ha)	Number of species	Shannon-Wiener's index of species diversity (H′)
V1	464	967	36	1.09
V2	618	1,288	36	1.02
V3	461	960	28	0.97
V4	388	1,213	22	0.85
V5	337	1,053	27	1.03
V6	467	1,459	20	0.67
V7	136	850	24	1.10
All the seven villages	**2,871**	**1,121**	**67**	**1.16**

The Sørensen-Dice's similarity index of forest tree species composition among the seven villages ranged from 0.40–0.69 (Table 4.4). Apart from the equal number of forest tree species found in the lower community forests (villages 1 and 2), the similarity index between these two villages was highest. This showed that tree species composition of the lower community forests was rather homogeneous. While the other villagers had lower values of the similarity index showing that their forest tree species composition was rather unique.

Table 4.4: Sørensen-Dice's similarity index of trees species composition among the seven community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

		Village						
		V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**
Village	**V1**	n/a	0.69	0.56	0.55	0.63	0.50	0.50
	V2	0.69	n/a	0.53	0.55	0.54	0.54	0.50
	V3	0.56	0.53	n/a	0.48	0.40	0.54	0.46
	V4	0.55	0.55	0.48	n/a	0.53	0.52	0.48
	V5	0.63	0.54	0.40	0.53	n/a	0.43	0.43
	V6	0.50	0.54	0.54	0.52	0.43	n/a	0.50
	V7	0.50	0.50	0.46	0.48	0.43	0.50	n/a

Diameter at breast height (DBH) classes among the seven villages are shown in Figure 4.5. Small DBH class from 4.5–15.0 cm of all the seven villages was lower than 80%. Dumrongrojwatthana (2004) reported that the deciduous forest with very high disturbance from clear cutting has DBH class from 4.5–15.0 cm in more than 90% of the cases. This showed that the Lainan's community forests were not strongly disturbed by clear cutting. Interestingly, a large tree (*Shorea obtusa*) with the DBH from 55.0–65.0 cm was only found in village 7. This could be inferred that the community forest of village 7 was not disturbed by clear cutting for several decades.

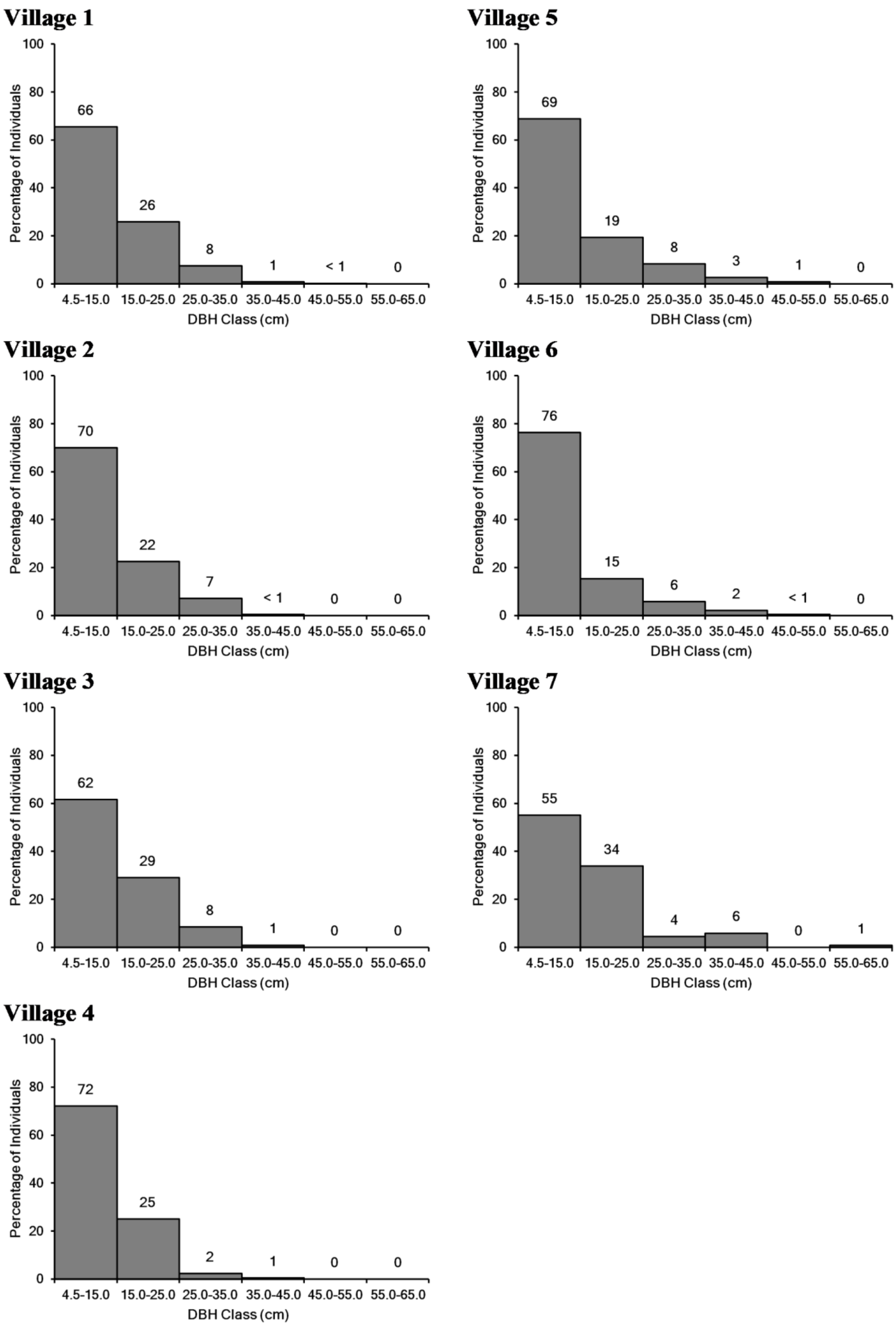


Figure 4.5: Diameter at breast height (DBH) class of trees found in each community forest at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

4.3.1.2 Tree species composition at the subdistrict scale

At the whole subdistrict scale, there were 2,871 individuals of forest trees belonging to 1 division (Angiospermae), 1 class (Dicotyledonae), 25 families, and 67 species with 1,121 trees/ha of density and 1.16 of H′, as shown in Table 4.3 and Appendix 7. Among these 67 tree species, there were 61 identified species and 6 unidentified species (Appendix 7). The top three dominant species determined by the species having the top three highest important value index (IVI) were as follows: *Shorea obtusa*, *Pterocarpus macrocarpus*, and *Shorea siamensis* with 16.36, 14.82, and 12.74 of IVI, respectively (Table 4.5).

Table 4.5: Number of individuals, relative density (RD), relative frequency (RF), relative dominance (RDo), and important value index (IVI) of each tree species found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

NO	Scientific name	Number of individuals	RD (%)	RF (%)	RDo (%)	IVI (%)
1	*Antidesma* sp.	1	0.03	0.36	< 0.01	0.13
2	*Aporosa* sp.	121	4.21	3.26	1.77	3.08
3	*Bauhinia* sp.	8	0.28	0.72	0.30	0.44
4	*Berrya mollis*	5	0.17	1.45	0.28	0.64
5	*Bombax ceiba*	22	0.77	1.09	0.42	0.76
6	*Canarium subulatum*	7	0.24	0.72	0.15	0.37
7	*Careya sphaerica*	11	0.38	2.17	0.08	0.88
8	*Cassia garrettiana*	6	0.21	0.72	0.08	0.34
9	*Catunaregam spathulifolia*	1	0.03	0.36	< 0.01	0.13
10	*Chukrasia velutina*	33	1.15	2.17	0.67	1.33
11	*Cleidion spiciflorum*	2	0.07	0.36	0.07	0.17
12	*Colona flagrocarpa*	60	2.09	3.26	2.64	2.66
13	*Cratoxylum* sp.	19	0.66	2.54	0.53	1.24
14	*Dalbergia cultrata*	5	0.17	0.72	0.12	0.34
15	*Dalbergia oliveri*	42	1.46	3.62	1.05	2.05
16	*Dillenia aurea* var. *aurea*	2	0.07	0.72	0.06	0.28
17	*Dioecrescis erythroclada*	2	0.07	0.36	0.03	0.15
18	*Diospyros ehretioides*	4	0.14	0.72	0.12	0.33

Table 4.5 (cont').

NO	Scientific name	Number of individuals	RD (%)	RF (%)	RDo (%)	IVI (%)
19	*Diospyros mollis*	2	0.07	0.36	0.03	0.15
20	*Diospyros rhodocalyx*	9	0.31	2.17	0.28	0.92
21	*Dipterocarpus obtusifolius*	66	2.30	1.09	3.00	2.13
22	*Dipterocarpus tuberculatus*	173	6.03	2.90	6.23	5.05
23	*Dipterocarpus* sp.	1	0.03	0.36	0.01	0.14
24	*Dolichandrone serrulata*	4	0.14	0.72	0.04	0.30
25	*Embelia subcoriacea*	5	0.17	0.72	0.06	0.32
26	*Eurya acuminata* var. *wallichiana*	5	0.17	0.72	0.25	0.38
27	*Garuga pinnata*	6	0.21	1.09	0.28	0.53
28	*Gluta* sp.	28	0.98	2.54	0.18	1.23
29	*Gmelina arborea*	4	0.14	0.72	0.50	0.46
30	*Haldina cordifolia*	41	1.43	2.54	0.66	1.54
31	*Hopea odorata* var. *odorata*	1	0.03	0.36	0.01	0.14
32	*Hymenodictyon orixense*	3	0.10	0.72	0.02	0.28
33	*Irvingia malayana*	7	0.24	1.09	0.25	0.53
34	*Lagerstroemia cochinchinensis* var. *ovalifolia*	2	0.07	0.36	0.05	0.16
35	*Lagerstroemia tomentosa*	1	0.03	0.36	< 0.01	0.13
36	*Lannea coromandelica*	51	1.78	3.26	0.86	1.96
37	*Litchi chinensis*	3	0.10	0.72	0.07	0.30
38	*Melientha suavis*	2	0.07	0.72	0.02	0.27
39	*Metadina trichotoma*	7	0.24	0.36	0.05	0.22
40	*Miliusa velutina*	1	0.03	0.36	0.06	0.15
41	*Millettia* sp.	4	0.14	0.72	0.03	0.30
42	*Mitragyna speciosa*	72	2.51	3.62	0.91	2.35
43	*Mitrephora vandaeflora*	3	0.10	0.36	0.02	0.16
44	*Morinda tomentosa*	21	0.73	2.90	0.43	1.35
45	*Parkia sumatrana*	12	0.42	1.09	0.85	0.78
46	*Phyllanthus emblica*	3	0.10	0.36	0.01	0.16
47	*Pterocarpus macrocarpus*	499	17.38	5.43	21.64	**14.82**
48	*Quercus* sp.	39	1.36	2.54	2.57	2.15
49	*Schleichera oleosa*	16	0.56	2.90	0.38	1.28
50	*Shorea obtusa*	729	25.39	4.71	18.98	**16.36**

Table 4.5 (cont').

NO	Scientific name	Number of individuals	RD (%)	RF (%)	RDo (%)	IVI (%)
51	*Shorea roxburghii*	21	0.73	1.45	0.86	1.01
52	*Shorea siamensis*	454	15.81	3.99	18.44	**12.74**
53	*Shorea* sp.	7	0.24	1.45	0.08	0.59
54	*Spondias pinnata*	6	0.21	1.45	0.44	0.70
55	*Strychnos nux-blanda*	14	0.49	2.17	0.21	0.96
56	*Tectona grandis*	105	3.66	2.90	7.25	4.60
57	*Terminalia chebula* var. *chebula*	8	0.28	1.45	0.08	0.60
58	*Terminalia mucronata*	15	0.52	1.81	1.07	1.14
59	*Vitex canescens*	18	0.63	2.90	0.46	1.33
60	*Vitex limoniifolia*	1	0.03	0.36	0.01	0.14
61	*Xylia xylocarpa* var. *kerrii*	33	1.15	2.54	3.61	2.43
62	Unknown 1	2	0.07	0.36	0.03	0.16
63	Unknown 2	1	0.03	0.36	< 0.01	0.13
64	Unknown 3	6	0.21	1.09	0.14	0.48
65	Unknown 4	1	0.03	0.36	< 0.01	0.13
66	Unknown 5	2	0.07	0.72	0.10	0.30
67	Unknown 6	6	0.21	0.36	0.13	0.23
	Summation of all tree species	**2,871**	**100**	**100**	**100**	**100**

At the whole subdistrict scale, DBH class of the community forest trees ranged from 4.5–65.0 cm (Figure 4.6). Although the forest trees with larger than 65.0 cm of DBH were not found in this study, the DBH class was very similar to the one reported in the conserved deciduous forest located at village 2 with very low disturbance from clear cutting (Dumrongrojwatthana, 2004). This suggested that the Lainan's community forests have not yet been in the climax stage and the ecological succession is still ongoing.

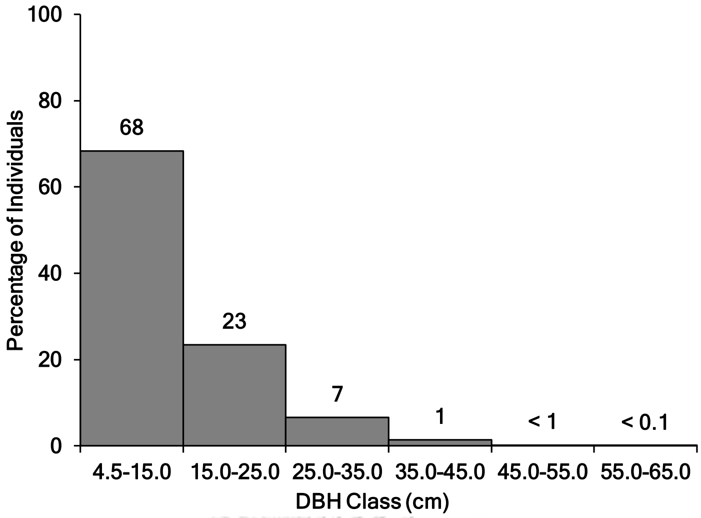


Figure 4.6: Diameter at breast height (DBH) class of trees found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

The forest trees with larger than 35.0 cm of DBH included *Dipterocarpus obtusifolius*, *D. tuberculatus*, *Gmelina arborea*, *Pterocarpus macrocarpus, Quercus* sp., *Shorea obtusa*, *S. siamensis*, *Tectona grandis*, *Terminalia mucronata*, and *Xylia xylocarpa* var. *kerrii*. Some of them were precious wood species, such as *Pterocarpus macrocarpus*, *Tectona grandis*, and *Xylia xylocarpa* var. *kerrii*.

4.3.1.3 Level of tree species richness

Table 4.6 shows the comparison of tree species richness between this study and references in the literature with diverse types of forest ecosystem. Dumrongrojwatthana (2004) reported the double number of tree species found in Nam Wa Sub-watershed (the conserved forest area of the Plant Genetic Conservation Project under the Royal Initiative of HRH Princess Maha Chakri Sirindhorn located nearby the community forests of village 2). The tree species composition was investigated by total count while quadrat sampling technique was applied in the field investigation of this case study. These different sampling methods probably made the tree species richness found in Dumrongrojwatthana (2004) higher than the one found in this case study.

Table 4.6: Comparison of tree species richness between this study and references in the literature.

Type of forest ecosystem and study site	Number of tree species	Sampling technique
Secondary dry dipterocarp and mixed deciduous community forests at Lainan Subdistrict, Nan Province (This study)	67 (25 families)	Quadrat sampling
Secondary deciduous forest at Nam Wa Sub-watershed, Lainan Subdistrict, Nan Province (Dumrongrojwatthana, 2004)	127	Total count
Primary mixed deciduous forest at Nam Yao and Nam Suad National Reserved Forest, Nan Province (Pibumrung, 2007)	n/a (28 families)	Quadrat sampling
A 37-year-old teak plantation established in the degraded mixed deciduous forest at Mae Yuak Plantation Station, Lampang Province, northern Thailand (Koonkhunthod *et al.*, 2007)	21	Quadrat sampling
Secondary dry dipterocarp forest at Khao Wong Community Forest, Chaiyaphum Province, northeastern Thailand (Ounkerd *et al.*, 2015)	62	Quadrat sampling
Secondary deciduous community forests at Waeng Nang Subdistirct, Maha Sarakham Province, northeastern Thailand (Pimsawan *et al.*, 2019)	41	Quadrat sampling
Secondary deciduous community forest at Nong Tin Village, Phatthalung Province, southern Thailand (Kiriratnikom and Sumpunthamit, 2013)	40	Quadrat sampling

Unfortunately, only the number of tree families (28 families) found in a natural forest ecosystem was reported by Pibumrung (2007), but it was higher than the one found in the Lainan’s community forests (25 families). However, the tree species richness in this case study was far higher than the degraded mixed deciduous forest reported by Koonkhunthod *et al*. (2007).

The data of tree species richness in Thailand's community forests found in the literature were mainly conducted in other regions of Thailand (Kiriratnikom and Sumpunthamit, 2013; Ounkerd *et al.*, 2015; Pimsawan *et al.*, 2019). That is to say there were very limited data of community forest structure in northern Thailand, and this case study is fulfilling a knowledge gap here. The tree species richness found in other community forests metioned above was lower than the Lainan's community forests, as shown in Table 4.6. This indicated that the tree species richness of the Lainan's community forests was rather high.

4.3.2 Richness of soil fauna

The richness of soil fauna among the seven villages ranged from 5 to 11 orders (Table 4.7). Village 4 had the highest richness of soil fauna with 0.91 of the diversity index while the lowest richness of soil fauna with 0.45 of the diversity index belonged to village 5.

Table 4.7: Diversity of soil fauna found in each community forest at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Village	Number of individuals	Number of orders	Shannon-Wiener's index of diversity (H′)
V1	16	5	0.58
V2	34	9	0.77
V3	19	7	0.65
V4	43	11	0.91
V5	31	6	0.45
V6	33	5	0.58
V7	17	5	0.59
All the seven villages	**193**	**18**	**0.92**

The Sørensen-Dice’s similarity index of soil fauna diversity ranged from 0.17–0.80, as shown in Table 4.8. Based on this similarity index, the diversity of soil fauna found in the villages 3, 5, 6, and 7 had rather similar.

Table 4.8: Sørensen-Dice’s similarity index of soil fauna diversity among the seven community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

		Village						
		V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**
Village	**V1**	n/a	0.43	0.17	0.38	0.36	0.40	0.40
	V2	0.43	n/a	0.50	0.40	0.53	0.43	0.57
	V3	0.17	0.50	n/a	0.44	0.77	0.67	0.67
	V4	0.38	0.40	0.44	n/a	0.47	0.38	0.25
	V5	0.36	0.53	0.77	0.47	n/a	0.73	0.73
	V6	0.40	0.43	0.67	0.38	0.73	n/a	0.80
	V7	0.40	0.57	0.67	0.25	0.73	0.80	n/a

At the subdistrict scale, there were 193 individuals of soil fauna belonging to 18 orders with 0.92 of Shannon-Wiener’s index of diversity (Table 4.7). Among these 18 orders, there were 16 identified orders and 2 unidentified orders, as shown in Appendix 8. Almost all the soil fauna found in this study were macro-soil fauna. Only few of them could be meso-soil fauna by their size. According to the classification of soil fauna reported by several authors (Lavelle, 1997; Coyne and Thompson, 2006; Lavelle *et al.*, 2006), only Acari (mites) and Collembola (collembolans) were found as the true meso-soil fauna, whereas the remains were juveniles of the macro-soil fauna.

The top three orders (macro-soil fauna) with the highest number of individuals found were Hymenoptera (ants), Isoptera (termites) and Coleoptera (beetles), respectively, as shown in Appendix 8. Two of them (termites and ants) play an important role as soil ecosystem engineers, defined as organisms that directly or indirectly modulate the availability of resources to other species by causing physical state changes in biotic or abiotic materials (Jones *et al.*, 1994; Jouquet *et al.*, 2006).

They also had multiple and complex processes in soil and interactions with other organisms (micro-soil fauna and plants). Based on these processes and interactions, Lavelle *et al.* (2016) classified three different types of soil ecosystem engineering processes that can be performed by both termites and ants: physical, community, and biochemical ones. These ecosystem engineering processes could deliver ecosystem functions and services (Figure 4.7).

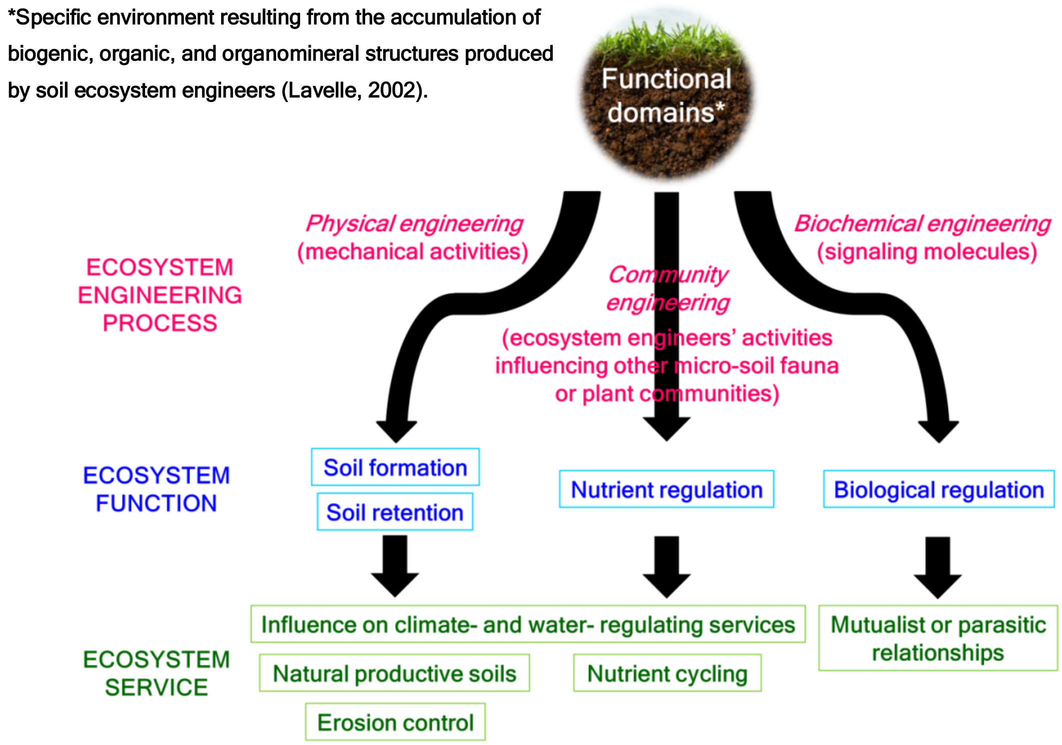


Figure 4.7: Termites and ants as soil ecosystem engineers and their ecosystem engineering processes relating to the delivery of soil ecosystem functions and services (adapted from Lavelle *et al*., 2016).

As termites and ants have a capability of movement in soil (which is very limited in the smaller soil fauna, in particular micro-soil fauna), they are significant determinants of physical engineering (the ability of organisms to alter the environments of other organisms by their mechanical activities) leading to the formation of diverse and abundant structures in soil (Lavelle, 1997; Lavelle *et al*., 2006).

Community engineering is the consequences of soil ecosystem engineers' activities leading to the changes of communities of dependent organisms (Lavelle *et al*., 2006). This process could be seen through termites in maintaining rather specific microbial communities within their gut. Furthermore, termite mounds could create foraging hotspots for several species, particularly herbivores leading the delivery of nutrient cycling in the ecosystem (Lavelle *et al*., 2016).

The last soil ecosystem engineering process is biochemical, signaling biochemical molecules emitted into the environment by the soil fauna alter resource availability of other organisms by increasing their resource use efficiency via changes in gene expression or through RNA modifications. This process is mainly related to the mutualistic or parasitic relationships between micro-soil fauna and plants. However, there are very few studies reporting the biochemical engineering process through macro-soil fauna (Lavelle *et al*., 2016).

4.3.3 Species richness of wild mushrooms

4.3.3.1 Species richness of wild mushrooms among the villages

Among the seven villages, wild mushroom species richness ranged from 24 to 55 species, as shown in Table 4.9. Interestingly, the village 3 had the highest wild mushroom species richness, but the second lowest value in Shannon-Wiener's species diversity index. Species diversity of a community depends on not only its species richness, but also its evenness defined as "the equitability in the distribution of individuals among a group of species in a community". That is higher species numbers with the individuals more evenly distributed among them contribute to higher diversity in a community (Odum and Barrett, 2005; Gurevitch *et al*., 2006). Therefore, the low species diversity index of wild mushrooms in village 3 was caused by its low species evenness even though its species richness was high.

Table 4.9: Number of wild mushroom species and Shannon-Wiener species diversity index (H′) among the seven community forests at Lainan Subdistrict, Wiang Sa District, Nan Province northern Thailand.

	Village						
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**
Number of wild mushroom species	33	28	55	24	31	37	35
Shannon-Wiener's index of species diversity (H′)	2.28	2.50	1.46	2.26	1.54	1.34	2.84

Among the seven villages, the Sørensen-Dice's similarity index of wild mushroom species diversity ranged from 0.38–0.64 (Table 4.10). The highest value of the similarity index was only 64% (resulting from the comparison between villages 2 and 5) while the values among other villages were lower than 60%. This showed that the wild mushroom species among the seven villages were low similarity, but high heterogeneity.

Table 4.10: Sørensen-Dice's similarity index of wild mushroom species diversity among the seven community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

		Village						
		V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**
Village	**V1**	n/a	0.59	0.52	0.42	0.47	0.54	0.44
	V2	0.59	n/a	0.55	0.50	0.64	0.52	0.51
	V3	0.52	0.55	n/a	0.38	0.51	0.48	0.40
	V4	0.42	0.50	0.38	n/a	0.51	0.46	0.34
	V5	0.47	0.64	0.51	0.51	n/a	0.56	0.45
	V6	0.54	0.52	0.48	0.46	0.56	n/a	0.47
	V7	0.44	0.51	0.40	0.34	0.45	0.47	n/a

4.3.3.2 Species richness of wild mushrooms at the subdistrict scale

At the subdistrict scale, there were 11,064 individuals of wild mushrooms belonging to 1 phylum (Basidiomycota), 1 class (Basidiomycetes), 7 orders, 19 families, 31 genera, and 105 species (Appendix 9) with 2.19 of H′. Among these 105 mushroom species, there were 98 identified mushrooms and 7 unidentified mushrooms. Regarding to the edible status, there were 53 edible species, 43 non-edible species, and 9 species with no edible report. Based on the species accumulation curve displayed by Figure 4.8, the accumulative number of wild mushroom species was stable since October 2015. This obviously showed that most of the wild mushroom species were covered in the field investigations during these nine months.

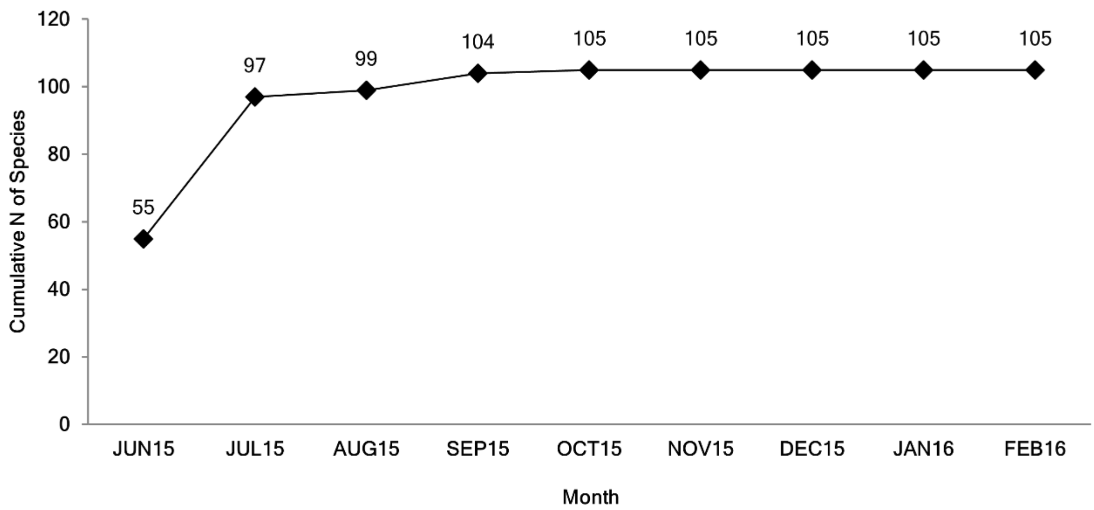


Figure 4.8: Wild mushroom species accumulation curve: species richness of wild mushroom found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand plotted against the length of time from June 2015 to February 2016.

The occurrence frequency (OF) of each wild edible species is displayed in Figure 4.9. Based on the experiences of local villagers, *Lentinus polychrous* could be found in the Lainan's community forests at the beginning of cool and dry season, as shown in Figure 4.4. However, during the field investigations, *L. polychrous* had the highest OF as it was found seven of the total nine months covering the period from wet season to cool and dry season. It was very small with less than 0.5 cm of its cap's diameter in wet season, but in cool and dry season, the cap diameter could be larger up to 7 cm.

Based on the OF, abundance status of each wild mushroom species could be categorized into the following four groups:

(i) very common (> 40% of OF): 13 species,

(ii) common (31–40% of OF): 14 species,

(iii) moderately common (21–30% of OF): 14 species, and

(iv) uncommon (≤ 20% of OF): 64 species.

As mentioned before in section 4.2.3 (NTFPs found in the community forests), almost all the wild mushroom species were mainly found in wet season starting from June and ending at the beginning of October, as shown in Figure 4.4. Therefore, the criteria for classifying a very common species were defined by at least 40% of the OF as this percentage of the OF was covered the period of four months in wet season.

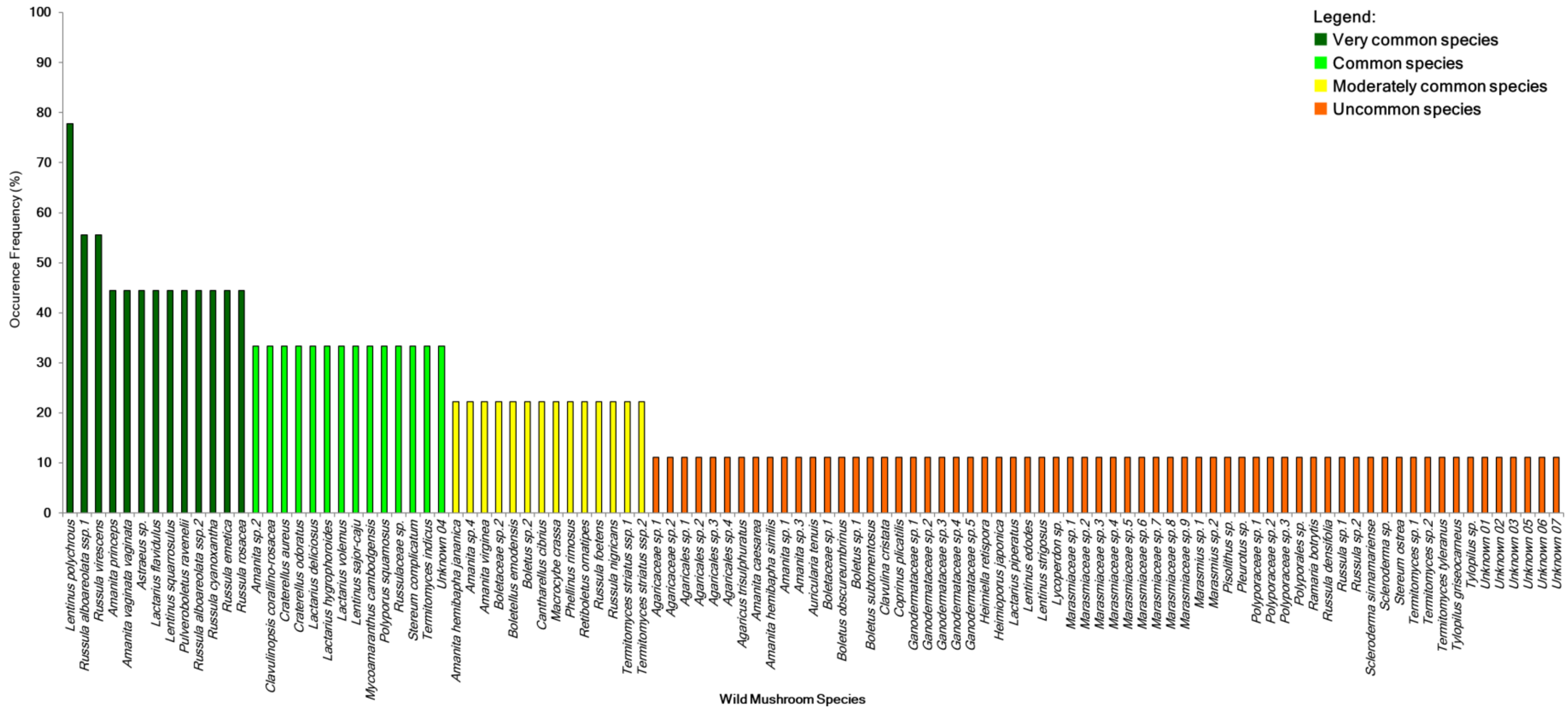


Figure 4.9: Occurrence frequency (OF) in percentage and abundance status, classified into four groups: very common (> 40% of OF), common (31–40% of OF), moderately common (21–30% of OF), and uncommon (≤ 20% of OF), of each wild mushroom species found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

4.3.3.3 Level of wild mushroom species richness

Table 4.11 illustrates wild mushrooms species richness between this study and references in the literature in various types of forest ecosystem. Most of wild mushrooms reported in the literature were identified in Phylum Basidiomycota while few of them belonged to Phylum Ascomycota. Among several studies, the Lainan's community forests had the highest number of edible mushroom species (Table 4.11).

In the similar forest type at Nam Wa Sub-watershed located very close to the Lainan's community forests (Yomyart, 2008), wild mushroom species richness was far lower than this case study. This is because only ectomycorrhizal fungi were collected in Yomyart (2008) while a large number of other wild mushroom species were probably not gathered.

In comparing to other community forests reported by Sansiri (2014), the wild mushroom species richness of Lainan's community forests was double-higher. Furthermore, it was also higher than natural forest ecosystems in northeastern Thailand (Wongchalee, 2009; Wongchalee, 2012). These indicated that the Lainan's community forests had high species richness for wild mushrooms. However, the wild mushroom species richness was double-lower compared with natural forest ecosystems in northern Thailand (Chanopas *et al.*, 2006; Butkrachang *et al.*, 2007).

Table 4.11: Comparison of wild mushroom species richness between this study and references in the literature.

Type of forest ecosystem and study site	Subject	Number of wild mushroom species	Number of edible species and its percentage of all the total species	Elevation (m amsl)	Sampling technique
Secondary dry dipterocarp and mixed deciduous community forests at Lainan Subdistrict, Nan Province (This study)	Wild mushroom	105 (Basidiomycota)	53 (50%)	< 330	Grid-based sampling
Secondary deciduous forest at Nam Wa Sub-watershed, Lainan Subdistrict, Nan Province (Yomyart, 2008)	Ectomycorrhizal fungi	30 (Basidiomycota)	n/a	< 265	Quadrat sampling
Secondary deciduous community forests at San Pa Tong District, Chiang Mai Province, northern Thailand (Sansiri, 2014)	Wild mushroom	63 (Basidiomycota)	45 (71%)	< 358	n/a
Secondary deciduous community forests at Mae Wang District, Chiang Mai Province, northern Thailand (Sansiri, 2014)	Wild mushroom	45 Basidiomycota: 44 Ascomycota: 1	29 (64%)	< 396	n/a
Primary mixed deciduous, dry dipterocarp and dry evergreen/pine forests at Doi Suthep-Pui National Park, Chiang Mai Province, northern Thailand (Butkrachang *et al.*, 2007)	Wild mushroom	258 Basidiomycota: 228 Ascomycota: 30	n/a	n/a	n/a

Table 4.11 (cont)'.

Type of forest ecosystem and study site	Subject	Number of wild mushroom species	Number of edible species and its percentage of all the total species	Elevation (m amsl)	Sampling technique
Primary forest at Doi Wiang La Wildlife Sanctuary, Mae Hong Son Province, northern Thailand (Chanopas *et al*., 2006)	Wild mushroom	177 Basidiomycota: 158 Ascomycota: 19	n/a	n/a	Simple random sampling
Primary mixed deciduous forest at Phu Phan National Park, Sakon Nakhon Province, northeastern Thailand (Wongchalee, 2009)	Wild mushroom	90 Basidiomycota: 82 Ascomycota: 8	16 (18%)	> 200	Quadrat sampling
Primary dry dipterocarp forest at Phu Phan National Park, Sakon Nakhon Province, northeastern Thailand (Wongchalee, 2012)	Wild mushroom	34 (Basidiomycota)	32 (94%)	> 200	Quadrat sampling
A 12-year-old *Dipterocarpus alatus* plantation at Chachoengsao Province, Eastern Thailand (Yomyart, 2008)	Ectomycorrhizal fungi	9 (Basidiomycota)	n/a	n/a	Quadrat sampling

4.3.3.4 Traditional knowledge to differentiate edible mushroom species from poisonous ones

Some edible mushroom species, such as *Amanita princeps*, *Russula emetic,* have morphological characteristics very similar to other poisonous species. To collect these edible species, local people used their traditional knowledge on edible mushroom identification (learnt from their parents or grandparents) to differentiate them from the poisonous species which have minor differences in their morphology, such as colour pattern, surface softness, or scent. Recently, very few young people (less than 18 y old) have come to harvest wild edible mushrooms in the community forest as most of them leave the village after completing their secondary education. The results indicated that the traditional knowledge regarding the identification of edible mushroom species will be lost in the near future. This created a new challenging issue at this site to maintain/transfer the traditional knowledge to those young people. Maintenance of the traditional knowledge was discussed in section 5.5.2 in CHAPTER V.

4.4 Regulation functions

4.4.1 Soil chemical characteristics

Among the seven villages, their soil chemical properties including pH, organic matter (%), total N (%), available P (ppm), and available K (ppm) were not much different, as shown in Table 4.12. Only soil pH was significantly different among the seven villages (ANOVA, P = 0.004) while organic matter, available P, and available K (excluded Total N as its quantity is fluctuated due to soil microbe activities) were not significantly different (ANOVA, P = 0.412, 0.142, and 0.689, respectively).

When considering the level of each soil chemical property, as shown in Table 4.13, all the seven villages had moderate in organic matter, but low/very low in available P and K. Regarding pH condition, the soil pH of only village 1 was in good condition, and the soil pH condition of villages 2 and 5 was moderate; while the other villagers had the poor soil pH condition. In overall, soil chemical fertility of only village 1 was moderate while the others had low soil chemical fertility (Table 4.13). The results showed that the lower community forests (villages 1 and 2) had better soil chemical fertility than the middle (village 3) and the upper community forests (villages 4 to 7).

Table 4.12: Soil chemical properties at the 0–20 cm depth of each community forest at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Village	**pH**	**Organic matter (%)**	**Total N (%)**	**Available P (ppm)**	**Available K (ppm)**
V1	6.06 ± 0.28^{a}	2.45 ± 1.01^{ns}	0.0890 ± 0.0341	1.70 ± 0.51^{ns}	22.39 ± 4.64^{ns}
V2	5.73 ± 0.35^{ab}	2.45 ± 0.97^{ns}	0.0883 ± 0.0337	3.77 ± 1.82^{ns}	16.75 ± 5.07^{ns}
V3	5.28 ± 0.09^{b}	3.30 ± 0.22^{ns}	0.1264 ± 0.0229	4.87 ± 2.09^{ns}	22.89 ± 4.29^{ns}
V4	5.29 ± 0.05^{b}	3.31 ± 0.15^{ns}	0.1284 ± 0.0171	5.10 ± 1.90^{ns}	29.12 ± 4.17^{ns}
V5	5.90 ± 0.22^{ab}	2.54 ± 0.65^{ns}	0.0901 ± 0.0235	2.27 ± 0.96^{ns}	23.09 ± 12.02^{ns}
V6	5.49 ± 0.26^{ab}	2.78 ± 0.55^{ns}	0.1042 ± 0.0325	3.29 ± 1.89^{ns}	23.46 ± 9.54^{ns}
V7	5.37 ± 0.17^{ab}	3.06 ± 0.22^{ns}	0.1126 ± 0.0124	4.07 ± 1.05^{ns}	25.50 ± 11.22^{ns}

NB: Different superscripts within a column indicate a significant difference ($P < 0.01$; Scheffe); ns = non significant difference.

Table 4.13: Level of soil chemical properties and soil chemical fertility of each community forest at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Village	**Level of soil chemical properties and their scores***				**Level of soil chemical fertility and its score****
	pH condition	**Organic matter**	**Available P**	**Available K**	
V1	Good (5)	Moderate (3)	Very 1ow (1)	Very 1ow (1)	**Moderate (10)**
V2	Moderate (3)	Moderate (3)	Low (2)	Very 1ow (1)	**Low (9)**
V3	Poor (1)	Moderate (3)	Low (2)	Very 1ow (1)	**Low (7)**
V4	Poor (1)	Moderate (3)	Low (2)	Very 1ow (1)	**Low (7)**
V5	Moderate (3)	Moderate (3)	Very 1ow (1)	Very 1ow (1)	**Low (8)**
V6	Poor (1)	Moderate (3)	Low (2)	Very 1ow (1)	**Low (7)**
V7	Poor (1)	Moderate (3)	Low (2)	Very 1ow (1)	**Low (7)**

*Organic matter (%), available P, and available K from Table 4.12 were used to be scored and classified their level based on the criteria from Land Development Department (see more details in Appendix 2).

**The criteria used for interpreting soil chemical fertility were provided in Appendix 2.

Although the results from statistical analysis confirmed that the amount of available P did not significantly different among the seven villages, their actual properties in terms of utilization for plant growth were still different based on the criteria from Land Development Department (Appendix 2). Therefore, classification of the level of soil chemical properties based on the criteria from Land Development Department was still necessary.

Table 4.14 displays soil chemical properties at the whole subdistrict scale of the Lainan's community forests and their comparison with the very close deciduous forest at Nam Wa Sub-watershed where the forest areas were classified into five different disturbance levels from clear cutting (Dumrongrojwatthana, 2004). The results showed that most of the soil chemical properties in this study (pH, organic matter, and available P and K) were similar to the ones reported in moderate disturbance level.

Decomposition is a key process for soil chemical fertility through its effects on both mineralization and humification. Macro-soil fauna are the major regulators of decomposition process in tropics and they also have major effects on soil physical structure, such as forming macropores and digging galleries and burrows (Lavelle *et al.*, 1992). As discussed in section 4.3.2, it significantly showed that macro-soil fauna, in particular termites and ants, play an important role in delivering several ecosystem functions relating to soil chemical fertility, such as soil formation and retention, and nutrient regulation.

Table 4.14: Comparison of soil chemical properties at the 0–20 cm depth between this study and reference in the literature.

Type of forest ecosystem and study site		pH	Organic matter (%)	Total N (%)	Available P (ppm)	Available K (ppm)
Dry dipterocarp and mixed deciduous community forests at Lainan Subdistrict, Nan Province (n = 21) (this study)		5.59 ± 0.35	2.84 ± 0.64	0.1056 ± 0.0276	3.58 ± 1.78	23.31 ± 7.54
Different disturbance levels from clear cutting in the deciduous forest at Nam Wa Sub-watershed, Lainan Subdistrict, Nan Province (Dumrongrojwatthana, 2004)	Very high (farmland) (n = 3)	6.75 ± 0.64	2.39 ± 0.47	0.1073 ± 0.0500	17.63 ± 19.67	57.87 ± 34.20
	High (abandoned farmland) (n = 3)	5.39 ± 0.13	1.40 ± 0.41	0.0618 ± 0.0230	2.42 ± 1.53	17.76 ± 5.79
	Moderate* (n = 3)	5.39 ± 0.08	3.14 ± 1.00	0.1198 ± 0.0440	3.75 ± 2.25	22.18 ± 3.10
	Low* (n = 4)	5.19 ± 0.18	2.62 ± 0.57	0.0910 ± 0.0200	2.13 ± 0.91	30.16 ± 9.42
	Very low* (n = 4)	5.08 ± 0.12	3.24 ± 1.75	0.1304 ± 0.0600	4.22 ± 2.71	32.68 ± 13.91

*The forest areas with different proportion of large trees (classified by their DBH > 45.0 cm). The forest area with very low disturbance had higher proportion of large trees than the areas with low and medium disturbance, and the forest area with low disturbance also had higher proportion of large trees than the area with medium disturbance.

4.4.2 Carbon storage in aboveground biomass

4.4.2.1 Aboveground carbon storage among the villages

Among the seven villages, aboveground carbon storage (ACS) estimated in 2014 ranged from 29 to 44 MgC/ha (Figure 4.10). The largest amount of ACS accounting for 44 ± 5 MgC/ha belonged to village 5 while village 1 had the smallest amount of ACS accounting for 29 ± 17 MgC/ha.

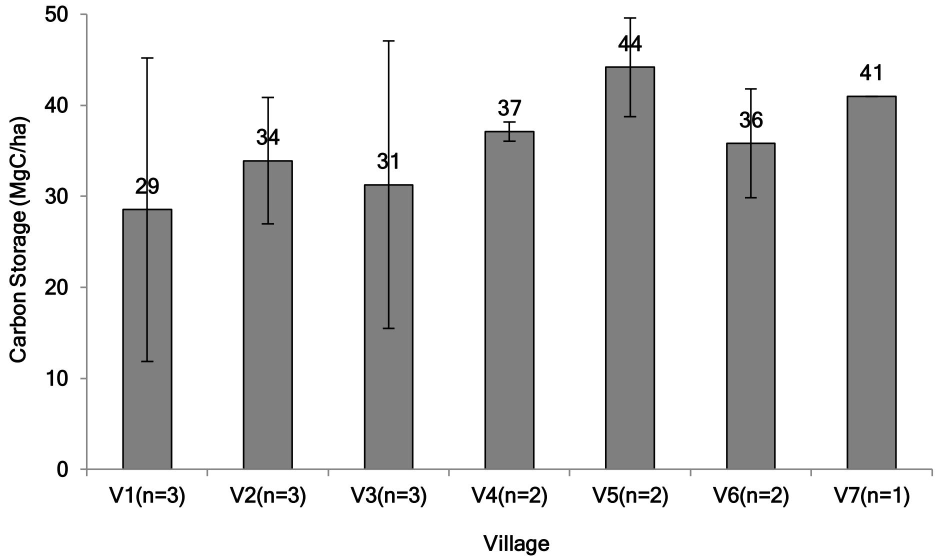


Figure 4.10: Carbon storage in aboveground biomass (MgC/ha) of each community forest estimated in 2014 at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

4.4.2.2 Aboveground carbon storage at the subdistrict scale

ACS at the whole subdistrict scale estimated in 2014 was 35 ± 10 MgC/ha. Among the 67 tree species, *Pterocarpus macrocarpus*, *Shorea obtusa*, and *Shorea siamensis* were the three dominant species with the highest capacity of ACS accounting for 7.53, 6.60, and 6.41 MgC/ha, respective (Figure 4.11).

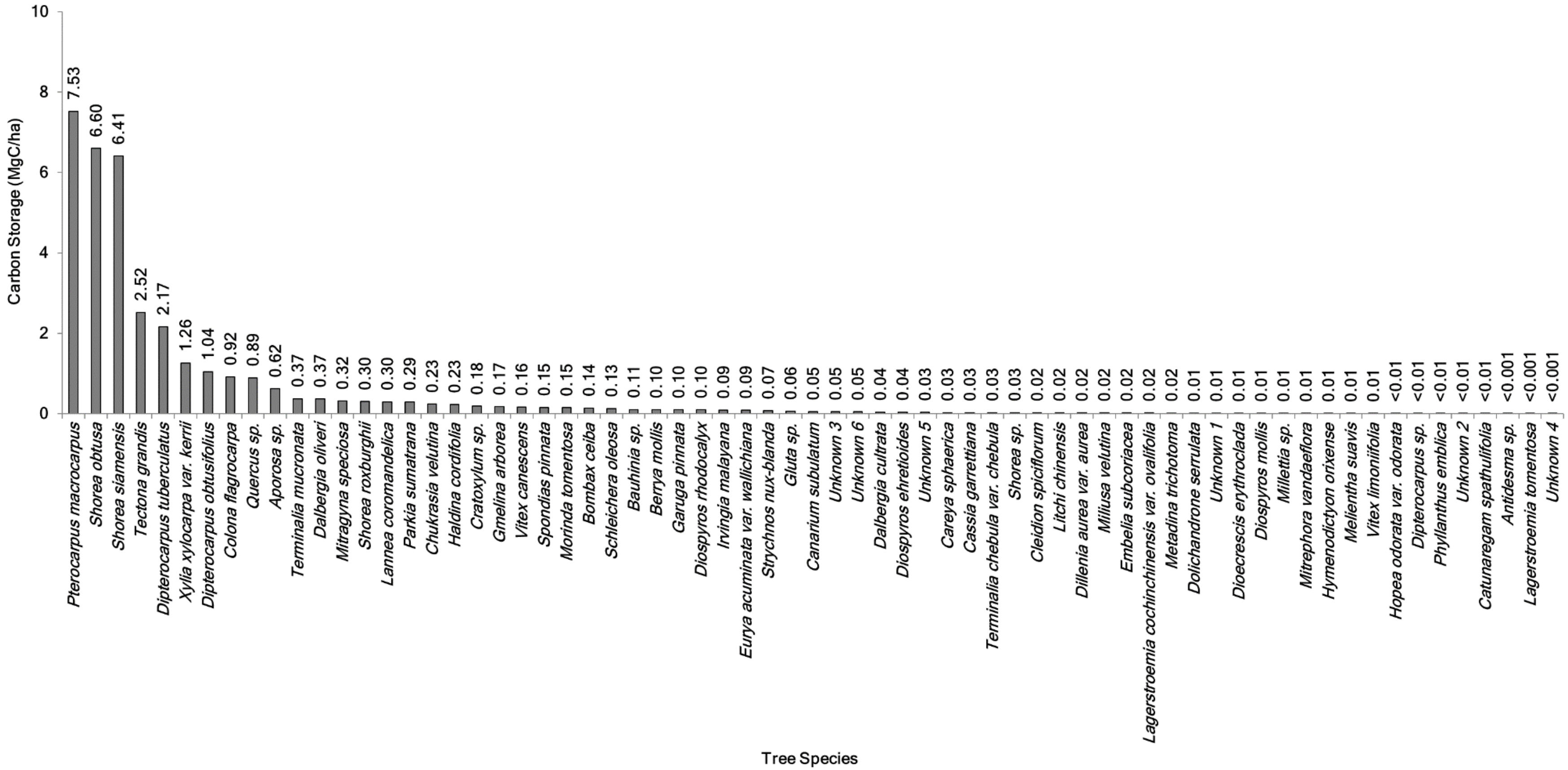


Figure 4.11: Carbon storage in aboveground biomass (MgC/ha) of each tree species in the community forests estimated in 2014 at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

4.4.2.3 Level of carbon storage in aboveground biomass

The comparison of ACS (MgC/ha) between this study and references in the literature is displayed in Table 4.15. Most of the studies selected Ogawa *et al.* (1965)'s allometric equations for calculating the ACS in a deciduous forest ecosystem. Only some of them used other allometric equations for the calculation, such as Ogino *et al.* (1964)'s allometry equations which are specific for the ACS calculation in a dry dipterocarp forest ecosystem. Almost all the studies estimated the carbon storage accumulated in aboveground biomass. Only the carbon storage reported by Kiriratnikom and Sumpunthamit (2013) included the quantity accumulated in forest tree roots (belowground carbon storage). The above-mentioned allometric equations were created about 55 years ago. To create the updated ones, there is a need of destructive sampling of a large number of vegetation covering wild range of size class, especially large trees in protected areas, which is sometimes illegal and often goes against the goal of conserving forests. Therefore, these allometric equations are still used for estimating ACS in nowadays (Viriyabuncha, 2003; Yuen *et al.*, 2016).

Table 4.15: Comparison of aboveground carbon storage (ACS) in MgC/ha between this study and references in the literature.

Type of forest ecosystem and location	ACS (MgC/ha)	Method used for calculating ACS
Secondary dry dipterocarp and mixed deciduous community forests at Lainan Subdistrict, Nan Province (This study)	35 ± 10	Allometry (Ogawa *et al*., 1965)
Secondary deciduous forest at Nam Wa Sub-watershed, Lainan Subdistrict, Nan Province (Dumrongrojwatthana, 2004)	28	Allometry (Ogawa *et al*., 1965)
Primary mixed deciduous forest at Nam Yao and Nam Suad National Reserved Forest, Nan Province (Pibumrung, 2007)	75 ± 7	Allometry (Ogawa *et al*., 1965)
Primary mixed deciduous forest at Namko Subdistrict, Phetchabun Province, lower northern Thailand (Kaewkrom *et al*., 2011)	49	Allometry (Ogawa *et al*., 1961)
Secondary dry dipterocarp forest at Khao Wong Community Forest, Chaiyaphum Province, northeastern Thailand (Ounkerd *et al*., 2015)	124 (conservation area) 90 (conservation area)	Allometry (Ogino *et al*., 1964)
Secondary deciduous community forests at Waeng Nang Sub-distirct, Maha Sarakham Province, northeastern Thailand (Pimsawan *et al*., 2019)	44	Allometry (Ogawa *et al*., 1965)
Secondary deciduous community forest at Nong Tin Village, Phatthalung Province, southern Thailand (Kiriratnikom and Sumpunthamit, 2013)	130 (including belowground biomass)	Allometry (Ogawa *et al*., 1965)

The ACS found in this study was rather similar to Dumrongrojwatthana (2004) where the forest type is very similar, and located very close to the Lainan's community forests. The study site of Dumrongrojwatthana (2004) was included several land-use types classified by different disturbance levels, particularly farmlands (very high disturbed area) and abandoned farmlands (high disturbed area), while the Lainan's community forests were not composed of such disturbed areas. This would make a little higher of ACS found in this study when comparing to

Dumrongrojwatthana (2004), although the forest type between these two studies was similar.

Pibumrung (2007) reported the ACS of 75 MgC/ha in a natural forest ecosystem of northern Thailand where is controlled by the law as a protected forest area, double higher than the 35 MgC/ha found in this study where the community forests are still under the disturbance from utilization of local people. This was corresponded to Ounkerd *et al*. (2015) reported that the ACS found in the conserved area was higher than in the utilized area.

According to Kaewkrom *et al*. (2011), the tree species composition in terms of tree density, tree dominant species (*Pterocarpus macrocarpus* and *Shorea siamensis*) based on the IVI, and the capacity of ACS in another natural forest ecosystem of lower northern Thailand was very similar to this case study, as shown in Table 4.5 and Figure 4.11, respectively. Interestingly, the ACS reported by Kaewkrom *et al*. (2011) was little higher compared to the ACS found in this case study. This indicated that the Lainan's community forests have high capacity of carbon storage in aboveground biomass which is close to the capacity of a natural forest ecosystem.

Similar to the level of tree species diversity mentioned in section 4.3.1.3, there were also very limited studies on the ACS in community forests of northern Thailand. Therefore, the ACS in the Lainan's community forests was compared with other community forests in other regions of Thailand, as shown in Table 4.15. Other community forests (Kiriratnikom and Sumpunthamit, 2013; Ounkerd *et al*., 2015; Pimsawan *et al*., 2019) had higher ACS than the Lainan's community forests. This indicated that the Lainan's community forests still have the potential to absorb additional atmospheric CO_2 in the future leading to global warming mitigation. Luyssaert *et al.* (2008) mentioned that old-growth forests can continue to accumulate carbon and contain large quantities of it. However, when forests are cleared, particularly in the tropics; much of carbon storage in tree biomass would be released to the atmosphere, especially from wood that is immediately burned. This is followed by carbon release through the oxidation of humus, in case the land is used for agriculture or urban development (Odum and Barrett, 2005; Baccini *et al*., 2012). This suggested that CFM at Lainan Subdistrict is very essential to avoid CO_2 emissions by deforestation and forest degradation in the future.

4.5 Production functions: productivity of the three major kinds of NTFPs

4.5.1 Productivity of the three major kinds of NTFPs among the villages

Larger community forests, located at the lower and middle elevations (villages 1 to 3), had a lower productivity of NTFPs but higher total volumes of production when comparing to the upper community forests (villages 4 to 7) (Table 4.16). Small upper community forests belonging to villages 5 and 6 had a high productivity of *M. suavis* and edible mushrooms but a low total production. These two community forests have a high potential to increase their production of NTFPs if their size expands in the future.

No production of queen broods of *O. smaragdina* was found in the upper community forests of villages 4 to 7. These community forests are surrounded by farmland and the use of insecticides in the neighboring fields may be one cause of this absence.

The NTFP harvesting pressure in the lower and middle community forests (villages 1 to 3) was high with more than 200 harvesters in each village (Table 4.1). Although these villages still provided a high production of NTFPs (Table 4.16), this is where the risk of future overharvesting exists. The upper community forests had a lower harvesting pressure because of their more difficult access and lower production of NTFPs.

Table 4.16: Productivity (PT) and annual production (P) of the three major NTFPs in each village of the Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

NTFP species	P and PT	Village number and elevation*						
		V1	V2	V3	V4	V5	V6	V7
		Lower	Lower	Middle	Upper	Upper	Upper	Upper
Melientha suavis	PT (kg/ha/y)	5	1	2	7	12	13	3
	P (kg/y)	124	150	279	9	33	21	19
Oecophylla smaragdina	PT (kg/ha/y)	19	23	**11	n/a	n/a	n/a	n/a
	P (kg/y)	507	2,873	83	n/a	n/a	n/a	n/a
Edible mushrooms	PT (kg/ha/y)	1	1	3	3	12	27	11
	P (kg/y)	32	91	408	30	33	44	60
Total harvesting areas* (ha)**		27	125	139	12	3	2	6

*Elevation is defined as lower (≤ 280 m amsl), middle (> 280, but ≤ 300 m amsl), and upper (> 300 m amsl).

**Village 3 has six community forest patches. Local people usually gather NTFPs in the largest patch covering 139 ha. Since this largest patch provided a very low production of queen broods of *O. smaragdina*, another 8 ha patch was selected to estimate this production.

***Harvesting areas were defined as areas actually used to gather NTFPs. Some areas, *e.g.* cliffs, stream beds, or areas too distant from the village or with low productions, did not provide suitable conditions for harvesting NTFPs.

4.5.2 Differences of NTFP productivity among the villages

This study clearly showed that the productivity of *M. suavis* in the upper community forests was higher than the productivity in the lower and middle community forests (Table 4.16). The growth and development of *M. suavis* in natural forest ecosystems is dependent on the availability of shading, water, and nutrients from its surrounding host plants (Amprayn *et al.*, 2013). Unfortunately, no studies are available in the literature so far to understand the influence of host plant species on the growth rate, particularly shoot development, of *M. suavis* in Thailand or even in Southeast Asia.

Lokkers (1990) stated that the rainfall, temperature, and forest components had a strong influence on the production of *O. smaragdina*'s queen broods. The development of the queen brood is particularly sensitive to low temperature with a threshold of 16.8 ± 0.7 °C. However, in this study, temperature is less important than rainfall as the mean daily temperature at Nan Province is always above 16.8 °C (Meteorological Department, 2019). The community forests of villages 1 to 3 were close to each other in a similar area characterized by a very similar forest tree structures (a mixture of dry dipterocarp and mixed deciduous forests in village 1; and dry dipterocarp forests in villages 2 and 3). This suggests that rainfall and temperature may not differ among these three community forests. Taylor and Adedoyin (1978) reported that *O. smaragdina* only inhabited areas of high tree density with interconnecting canopy, so a likely explanation for the differences in productivity of *O. smaragdina*'s queen brood among these three villages could be the influences of tree density and canopy cover, but additional studies will be needed to confirm this.

Numerous interacting factors and conditions influence wild mushroom yields and include environmental (rainfall, air and soil temperatures, evapotranspiration, relative humidity, and water deficits or excesses), sylvicultural (tree species, stand age, density, distribution, and canopy cover), ecological (community composition, competitive interactions, and reproductive strategies), landscape (altitude, aspect, and slope), and anthropogenic (timber removal, controlled burns, wildlife management strategies, grazing, and introduced species) factors (Martínez de Aragón *et al.*, 2007). Weather conditions clearly played a key role in relation to the growth and productivity of mushrooms at our research site, but it was not possible to conclude which combined factors interacted with the productivity of edible mushrooms at completion of such a short-term study (Egli, 2011). Interestingly, most edible mushrooms in this study (at least 35 out of the 53 species) were ectomycorrhizal fungi (Tedersoo *et al.*, 2010), which are a symbiotic relationship between the soil fungi and the fine roots of their respective host trees (mostly belonging to Dipterocarpaceae). The dominant tree species in Lainan's community forests were *Shorea obtuse* Wall, *Shorea siamensis* Miq., *Quercus* sp., and *Dipterocarpus obtusifolius* Teijsm. ex Miq., which are host trees for ectomycorrhizal fungi. Further longer-term and in-depth studies are needed to examine the factors related to mushroom productivity and the influences of such host trees on the yields of ectomycorrhizal mushrooms.

4.5.3 Productivity of the three major kinds of NTFPs at the subdistrict scale

At the whole subdistrict scale, the productivities of *M. suavis,* queen broods of *O. smaragdina*, and edible mushrooms were 2, 12, and 2 kg/ha/y, respectively. The *M. suavis* production was highest in May at 310 kg (Figure 4.12a). Wild fires, which occur in these deciduous community forests at the end of the dry season, in April, stimulate *M. suavis* to produce new branches and leaves after shedding their burned leaves. Sribandit (2007) reported that the larva of *O. smaragdina* start to transform (metamorphose) into adults in March and the number of queen broods then decreased until the end of the dry season in May. This decrease in the production of queen broods of *O. smaragdina* was seen in this study as soon as April, as shown in Figure 4.12b. The production of edible mushrooms was high in the wet season (June to October), but very low in the cool and dry season (November to February) (Figure 4.12c). Fifty-two edible mushroom species were harvested in the wet season (Figure 4.13). *Macrocybe crassa*, *Amanita princeps*, and *Russula emetica* were the three dominant species collected with the highest productivities of 0.46, 0.36, and 0.20 kg/ha/y, respectively. *Lentinus polychrous* was an edible mushroom species harvested in the cool and dry season (Figure 4.13). This species displayed a very low productivity (0.03 kg/ha/y) as it needs to grow on coarse wood debris (Karunarathna *et al.*, 2011), which are rarely found in the community forests due to the prohibition of logging activities.

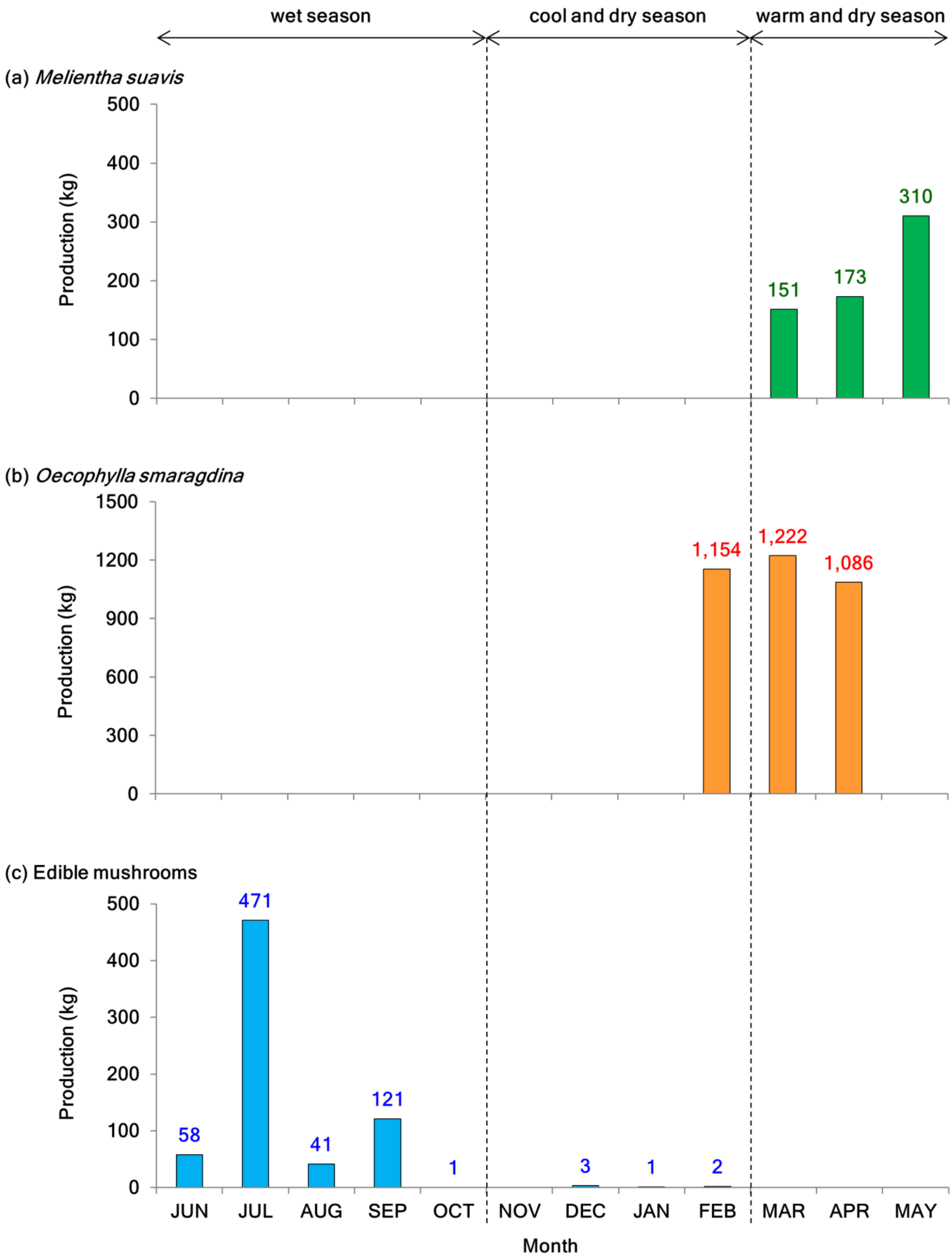


Figure 4.12: Monthly production (kg) of the three major NTFPs gathered from June 2015 to May 2016 at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand: (a) *Melientha suavis*, (b) queen broods of *Oecophylla smaragdina*, and (c) edible mushrooms.

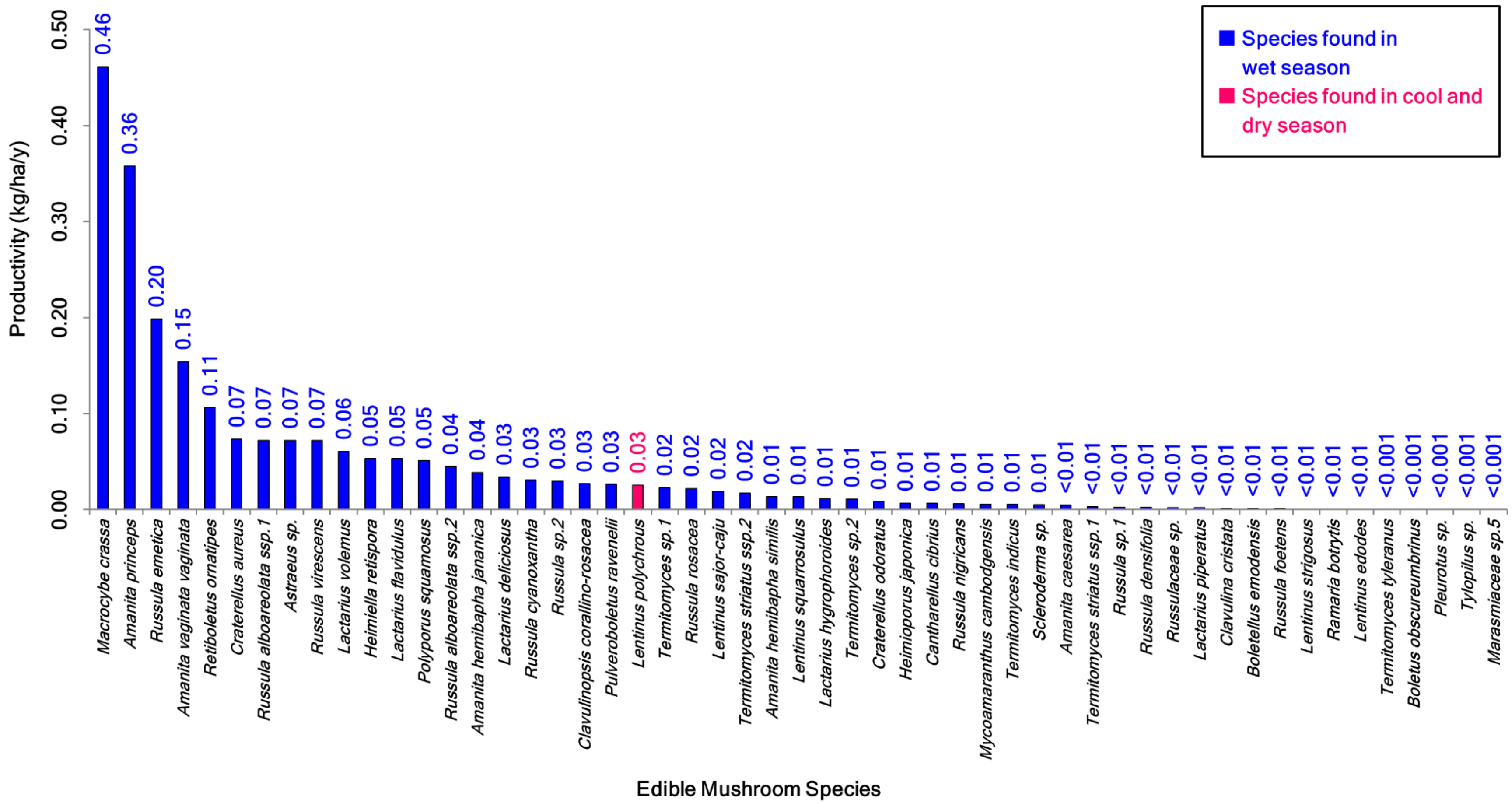


Figure 4.13: Productivity (kg/ha/y) of each edible mushroom species gathered from June 2015 to May 2016 at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

4.5.4 Level of NTFP productivity

Sribandit (2007) reported that the productivity of *O. smaragdina*'s queen broods was only 0.59 kg/ha/y, but in our study the productivity at the whole subdistrict level was much higher (20-fold) at an estimated at 12 kg/ha/y. However, Sribandit (2007) examined a large heterogeneous area of 78 km^2 in Nakhon Ratchasima Province of northeastern Thailand, which was only partly used for NTFP harvesting and was composed of natural deciduous dry dipterocarp, dry evergreen and disturbed forests due to urbanization, as well as plantations and orchards. In our study, the field data collection was conducted in much smaller areas of dry dipterocarp and mixed deciduous forests covering only 312 ha. These areas were less heterogeneous (with respect to the types of forest and land-use activities) and covered only NTFP harvested areas leading to the higher productivity.

Chanopas *et al.* (2006) identified more than 123 edible mushroom species in a natural forest ecosystem of northern Thailand, far more than the 53 species found in this study. Most natural forest ecosystems in Thailand are protected under the law and NTFP harvesting is not permitted, but it is not illegal in community forests. Harvesting of NTFPs affects ecological processes at both individual and population levels, such as changes in the survival rate, growth, and reproduction of harvested NTFPs (Ticktin, 2004). At Lainan's community forests, some damage while gathering NTFPs occurred occasionally due to the harmful harvesting practices of outsiders, such as using a small rake (called 'waek' in the local language) to search for *Astraeus* sp. on the forest ground. This practice destroys the mushroom sporophytes prior to spore release leading to a potential decline in the mushroom population and species diversity. However, Kullama and Sinunta (2011) reported similar numbers of edible mushrooms (54 species) found in the central markets of 11 districts in Nan Province. These species were probably the only ones with high market value, while the other species may be collected for local harvesters' household consumption only.

No data are available in the literature to compare the productivity of *M. suavis* with other case studies and our survey is filling a knowledge gap here. The availability of such quantitative data for the three major NTFPs is very important to monitor and evaluate existing management practices, or to support the design of an environmental conservation policy (Ticktin, 2004; Schulp *et al.*, 2014).

4.5.5 Typology of NTFP harvesters, and their practices and related decision-making processes

The NTFP harvesters could be classified into the following four types: (A) landless villagers, (B) small and medium landholders, (C) larger landholders, and (D) outsiders. The characteristics of these different types of NTFP harvesters are presented in Table 4.17. Based on the purpose of harvesting, type B harvesters were split into the two sub-types of B1 and B2 harvesters who gathered NTFPs for sale and for self-consumption, respectively. The volume of NTFPs harvested by outsiders was not available because they could not be interviewed directly. The local regulations outlaw outsiders from gathering NTFPs in the community forests and so they generally stay away from people they do not know. Table 4.18 displays the different practices of these types of NTFP harvesters. Type A had the highest harvest frequency (d/week), duration of harvest (h/harvesting d), and amount harvested (kg/harvesting d) among the local harvesters. The amount harvested by type A harvesters remained lower compared to outsiders, since the latter face higher costs and longer travelling times and so did their best to maximize the amount of NTFPs harvested per trip. The volume of *M. suavis* used for self-consumption by type A harvesters (0.2–0.3 kg/harvesting d) was lower than the other types because of the lower annual production of the whole subdistrict (635 kg/y), compared to queen broods of *O. smaragdina* and edible mushrooms, leading to a high market demand for *M. suavis*. The volume of queen broods of *O. smaragdina* used for self-consumption by type C harvesters (0.1–0.2 kg/harvesting d) was lower than the other types because of the shorter duration of harvest (less than 1 h/ harvesting d). As the annual cropping year starts in mid-April, type C harvesters with larger farms are busy preparing their land for cultivation and do not allocate much time to harvest queen broods of *O. smaragdina*. In case they need a higher volume of queen brood of *O. smaragdina*, they buy it from type A or B1 harvesters.

Table 4.17: Characteristics of the four types of NTFP harvesters at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

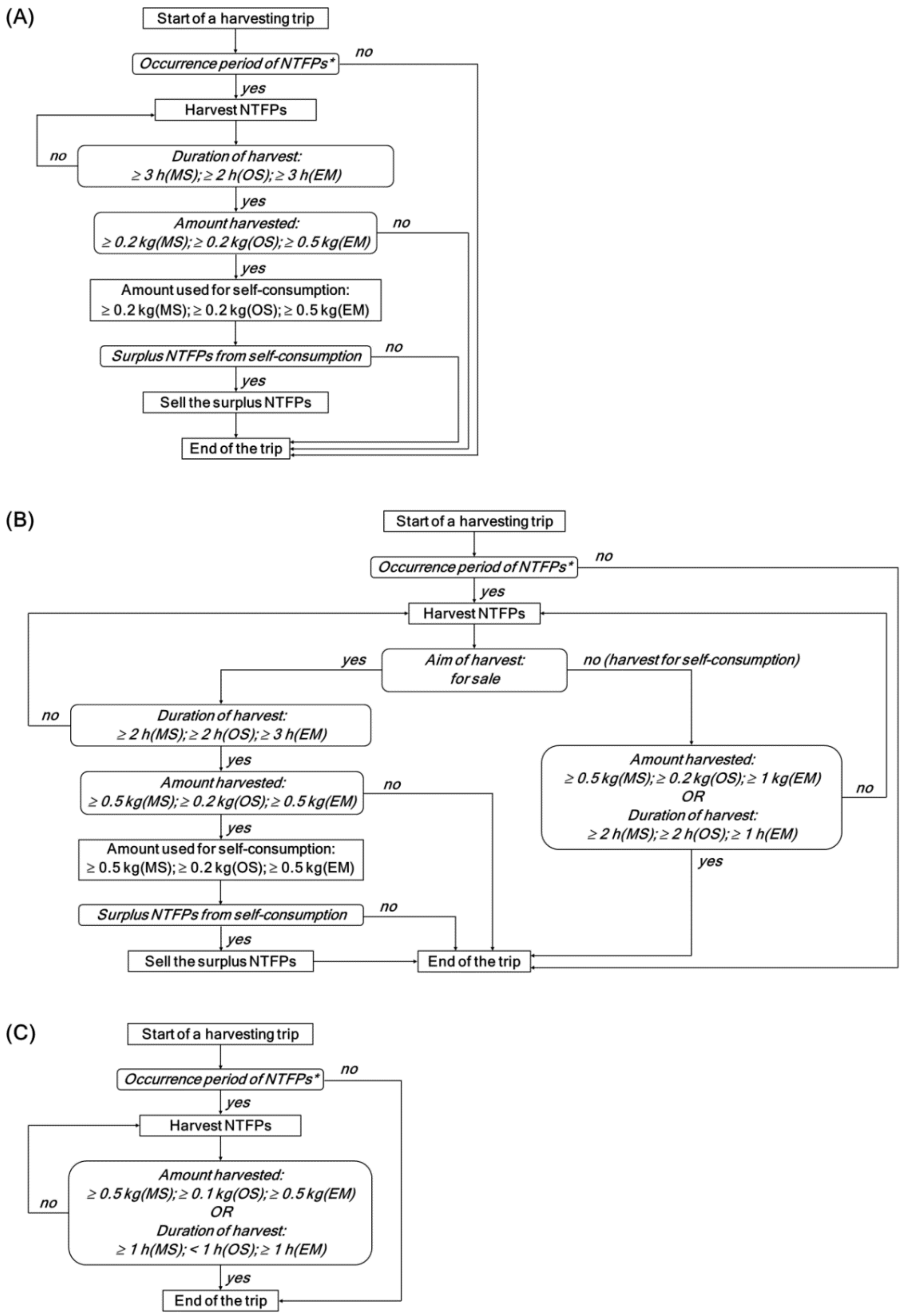
Criteria	Type of NTFP harvester				
	A. Landless villager	B. Small and medium landholder		C. Larger landholder	D. Outsider
		B1	B2		
Farm size (ha)	0	≤ 5.6	≤ 5.6	> 5.6	n/a
Importance of NTFP collection activity	High	Medium	Medium	Marginal	Varying
Purpose of collection	For sale	For sale	For self-consumption	For self-consumption	For sale
Harvest periods (months)	≥ 8	≤ 7	≤ 7	≤ 6	≤ 6
Overall volume harvested (in kg/y)					
Melientha suavis	≥ 128	≥ 16	≥ 6	≥ 4	n/a
Queen broods of *Oecophylla smaragdina*	≥ 128	≥ 8	≥ 2.4	≥ 0.4	n/a
Edible mushrooms	≥ 320	≥ 96	≥ 16	≥ 8	n/a

Table 4.18: Harvesting practices of the four types of NTFP harvesters at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Type of NTFPs	Type of NTFP harvester				
	A*	B		C	D
		B1	B2		
I. *Melientha suavis*					
Harvest period	Feb–May	Mar–Apr	Mar–May	Mar–Apr	Mar–Apr
Harvest frequency (d/week)	4–6	2–3	1–2	1–2	n/a
Duration of harvest (h/harvesting d)	3–4	2–3	2–3	1–2	n/a
Amount harvested (kg/harvesting d)	2.0–5.0	1.0–2.0	0.5–1.0	0.5–1.0	4.0–6.0
Amount used for self-consumption (kg/harvesting d)	0.2–0.3	0.5–1.0	0.5–1.0	0.5–1.0	n/a
II. Queen brood of *Oecophylla smaragdina*					
Harvest period	Feb–May	Mar–Apr	Mar–May	Mar–Apr	Mar–Apr
Harvest frequency (d/week)	4–6	1–2	1–2	2–3 d/month	n/a
Duration of harvest (h/harvesting d)	2–4	2–3	2–3	< 1	n/a
Amount harvested (kg/harvesting d)	2.0–3.0	1.0–2.0	0.2–0.3	0.1–0.2	3.0–6.0
Amount used for self-consumption (kg/harvesting d)	0.2–0.3	0.2–0.3	0.2–0.3	0.1–0.2	n/a
III. Edible mushrooms					
Harvest period	Jun–Dec	Jun–Sep Oct–Dec(optional)**	Jun–Sep	Jun–Sep	Jun–Sep
Harvest frequency (d/week)	4–6	2–3	1–2	1–2	n/a
Duration of harvest (h/harvesting d)	3–4	3–5	1–2	1–2	n/a
Amount harvested (kg/harvesting d)	4.0–5.0	3.0–5.0	1.0–2.0	0.5–1.0	5.0–10.0
Amount used for self-consumption (kg/harvesting d)	0.5–1.0	0.5–1.0	1.0–2.0	0.5–1.0	n/a

*Landless villagers could harvest NTFPs twice a day but the total duration of harvest and amounts of NTFPs harvested were estimated based on the sum of their daily harvesting trips.
**During this period with a low production of edible mushrooms, some B1 type harvesters preferred to start harvesting annual crops on their farms.

Only the decision-making processes of types A, B, and C harvesters are presented in Figure 4.14 as such information from type D harvesters who avoid the interviews could not be collected. The main parameters used by local harvesters to make their harvesting decisions were the occurrence period of NTFPs, the duration of harvest, and the amount harvested. Type A harvesters decided to perform a second daily harvest when a large amount of NTFPs was available. That is to say when the first harvest of the day was more than 2 kg for both *M. suavis* and queen broods of *O. smaragdina* and not less than 4 kg for edible mushrooms. Types B2 and C harvesters stopped gathering NTFPs when they had enough products for their self-consumption. When only a small amount of NTFPs were available, they stopped gathering NTFPs after spending more than 1 h gathering them, depending on which type of harvesters and what kind of NTFPs, as shown in Figure 4.14B and C, even if they could not collect enough products for their self-consumption needs.



*The occurrence period of each kind of NTFP is shown in Figure 4.4.

Abbreviations: MS = *Melientha suavis*

OS = queen broods of *Oecophylla smaragdina*

EM = edible mushrooms

Figure 4.14: Decision-making processes of the three types of NTFP harvesters at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand: (A) landless villagers, (B) small and medium landholders, and (C) larger landholders.

4.5.6 NTFPs support for resource-poor households

In the case of landless villagers, NTFPs can be harvested continuously for eight months, from February to September (Figure 4.12), and provide these resource-poor families with regular cash income during this period while satisfying part of their basic household consumption needs. During the remaining four months, corresponding to the harvest period of key crops (maize, rice, etc.), their family workers generate further cash income through wage-earning activities carried out on larger type C farms.

4.5.7 Access to NTFPs

Some studies found that NTFP harvesting can negatively affect ecological processes at many levels, particularly at the local community one (Ticktin, 2004). Several countries, especially European countries, such as France and Italy, authorize and regulate NTFP harvesting with a permit allowing the gathering of a limited amount of products. Such types of regulation can be used to control not only individuals, but also the collective access of harvesters to NTFPs (Górriz-Mifsud *et al.*, 2017). In the lower and middle community forests (villages 1 to 3), local people have been attempting to prevent outsiders from harvesting NTFPs in their community forests for many years to avoid overexploitation. A harvesting permit may be used to regulate the number of harvesters as well as the periods and frequency of harvesting visits to decrease the pressure on these resources. This could be an innovative conservation practice to be tested in the future with local stakeholders (all types of harvesters, village headmen, CFM committees, SAO staff members, other villagers, and researchers).

4.6 Conclusion

Lainan’s community forests have officially been operating for nearly half a century. Although each village had its own CFM rules and regulations, the total community forest areas were decreased by at least 70% during the last few decades. Level of soil chemical fertility in the Lainan’s community forests based on their soil chemical properties was low/moderate. The community forests at this site had ability to store carbon in their aboveground forest tree biomass accounting for 35 ± 10

MgC/ha. There were 67 tree species, 18 orders of soil fauna, and 105 wild mushroom species found in the community forests. Among these 105 wild mushroom species, there were 53 edible species, 43 non-edible species, and 9 species with no edible report.

Regarding the provision of food to local livelihood, there were 183 different NTFPs found in the community forests. Among these diverse NTFPs, *Melientha suavis*, queen brood of *Oecophylla smaragedina*, and wild edible mushrooms were identified as the three common NTFPs at this site based on their high farm gate prices (could be up to 300 THB/kg) and their availability, and the CFM rules and regulations to prohibit wildlife hunting in the community forests. The productivity of these three major types of NTFPs was 2, 12, and 2 kg/ha/y for *M. suavis*, queen broods of *O. smaragdina*, and edible mushrooms, respectively. Four types of harvesters as (A) landless villagers, (B) small and medium landholders, (C) larger landholders, and (D) outsiders were identified with different harvesting practices. The three types of local harvesters displayed different decision-making processes to gather NTFPs depending on the three parameters of the resource occurrence period, the duration of harvest, and the amount harvested.

For over two successive years to complete the ecological field investigations as 'the ecologically conventional assessment' of the Lainan's community forest ecosystem functions, the outcomes of this activity provided a researcher-based understanding on the community forest SES. To build an integrated understanding between local people and the researcher on the community forest SES, 'the participatory assessment' was therefore carried out in the subsequent phase (CHAPTER V).

CHAPTER V
COMMUNITY FOREST ECOSYSTEM STATUS BASED ON PARTICIPATORY ASSESSMENT

5.1 Scoring the community forest ecosystem status

Figure 5.1 recapitulates the calibrated total score of each main community forest ecosystem function and the status score of each community forest. While the raw scores in all selected community forest ecosystem functions is provided in Appendix 10.

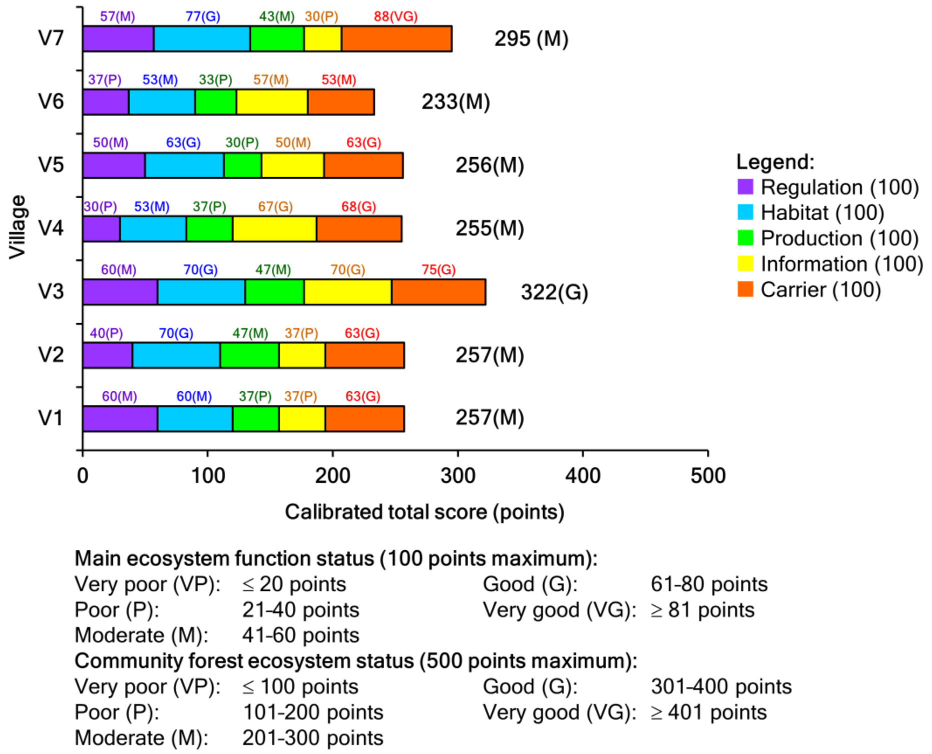


Figure 5.1: Calibrated total scores from the participatory assessment of community forest ecosystem functions and their status of each village at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Among the seven villages, the status score of each community forest ranged from 233 to 322 of 500 points, as shown in Figure 5.1. The highest score (322 points) belonged to village 3 while the lowest one (233 points) belonged to village 6. Based on these status scores, the results showed that the community forest ecosystem status of only villages 3 was good while the status of other villages was moderate. This corresponded to the island biogeography theory explaining that a large forest area (similar to village 3) has more stable ecosystem functioning compared with smaller ones (Laurance, 2008). When considering the calibrated total scores of five main community ecosystem functions across all the seven villages, the results showed that village 3 had the highest calibrated total scores of information (70 points), regulation (60 points), and production (47 points) functions. Interestingly, village 7 had the second highest status score with 295 of 500 points which is very close to be identified its community forest ecosystem status as 'good', although its community forest area is the second smallest in the Lainan Subdistrict with only 7 ha (Table 4.1). Moreover, among the seven villages, it also had the highest calibrated total scores in carrier (88 points) and habitat (77 points) functions. As mentioned in section 4.3.1.1, the community forest structure of village 7 had the highest proportion of large trees with the DBH of 55.0–65.0 cm. That is to say the community forest structure of this village was relatively closer to a climax stage of ecological succession than the other villages resulting in the high score of habitat functions.

Similar to several regions of the world, the local people at Lainan Subdistrict mentioned during the preliminary field surveys that a major benefit that they can obtain from their community forests is food sources (production functions). Therefore, most of the local evaluators expected that the total calibrated total score in production functions of their village would be high, especially in village 3 where large amount of NTFP productions can be provided due to large areas of the community forests (Table 4.16). However, among the five main community forest ecosystem functions, most of the villages had the lowest calibrated total score for production functions, ranging from 30 to 47 of 100 points (Figure 5.1), because not only food were considered in the scoring criteria of the production functions, but also raw materials and medicinal resources which all villages had low scores in these two items (Appendix 10).

5.2 Community forest degradation risks

Based on the focus group discussion, there were five community forest degradation risks at this site including forest encroachment, occurrence of wildfire, waste dumping, intrusion of outsiders harvesting NTFPs, and loss of the traditional knowledge (Table 5.1). When considering the number of degradation risks found in each community forest among the seven villages, the results showed that the larger, lower and middle community forests (villages 1 to 3) had the higher number of degradation risks, with at least four out of five risk items, compared to the small and upper community forests (villages 4 to 7) showing only one or two risk items (Table 5.1). This is because the lower and middle community forests are easy to access due to the occurrence of a rural road passing the edges of these forests. While the upper ones are more difficult to reach as they are located on hilly land.

Table 5.1: Community forest degradation risks during 2013–2017 in each village of Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Village	Community forest degradation risks during 2013–2017				
	Forest encroachment	**Occurrence of wildfire**	**Waste dumping**	**Intrusion of outsiders harvesting NTFPs**	**Occurrence of children harvesting NTFPs with their parents**
V1	Yes	Yes	Yes	Yes	Yes
V2	No	Yes	Yes	Yes	Yes
V3	Yes	Yes	No	Yes	Yes
V4	No	Yes	No	No	No
V5	No	Yes	No	No	Yes
V6	Yes	Yes	No	No	No
V7	No	No	Yes	No	Yes

During 2013–2017, forest encroachment occurred once in villages 1, 3, and 6. It was clear that road construction is one factor correlating to forest destruction (Mäki *et al.*, 2001). Therefore, it was not surprising that the lower and middle community forests were still facing with the risk of forest encroachment. As mentioned by the local evaluators, expansion of agricultural areas caused the community forest encroachment in village 6. This suggested that the upper ones surrounded by large farmed areas are also facing the risk of forest encroachment.

Easy access to the lower and middle community forests due to availability of a rural road was also the cause of waste dumping. The local evaluators stated that waste dumpling occurred in villages 1 and 2 more than 10 times during 2013–2017. Although occurrence of waste dumping was not reported in village 3, it was found by the researchers during the preliminary field surveys.

There were outsiders coming from other subdistricts or even other provinces to harvest NTFPs in the lower and middle community forests (villages 1 to 3) since these forests could provide high production of NTFPs (Table 4.16). As reported in section 4.5.5, large amount of NTFP production was gathered by these outside harvesters since they face higher costs and longer travelling times per trip compared to the local harvesters. This would create the risk of overharvesting in the near future.

Very few local NTFP harvesters (only 2–4% of the total households in each village) brought their children to harvest NTFPs in the community forests with them. Among the upper village (villages 4 to 7), village 4 had the largest total number of households, but there were no ones bringing their children to harvest NTFPs with them. At the end of the field investigations, the local evaluators told that most young villagers (less than 18 y old, including some of their children) moved to live and work outside of their village, particularly in urban areas, since they believed that the job opportunities in urban areas were higher than the countryside like Lainan Subdistrict. The author also noticed that all the local evaluators in this study are middle-aged people (from 18 to 60 y old) without any young ones. Furthermore, the local evaluators said that they learnt the traditional knowledge regarding local NTFPs (e.g. vernacular names of these resources and their benefits to local people) while they were harvesting NTFPs in the community forests with their parents or grandparents. This traditional knowledge has never been systematically documented. The results indicated that future use of the local NTFPs by the young people's generations is threatened and this site is confronting with the loss of traditional knowledge which is corresponded to the findings reported in section 4.3.3.4.

Among the five degradation risks, wildfire occurred in almost all the villages at least once and up to three times during 2013–2017. The local people mentioned that this wildfire anthropogenically occurred in warm and dry season (in March and April each year). Some NTFP harvesters believed that fire could increase the production of

M. suavis and some edible mushroom species. However, Whelan (2002) reported that fires undoubtedly caused injuries and mortalities to several individual organisms, both plants and animals. Additionally, heat from fire could also decrease availability of NTFPs, such as edible mushrooms and queen brood of *O. smaragdina* (Kennedy *et al.*, 2012).

5.3 Characteristics of participatory assessment tool

The characteristics of the participatory assessment tool compared with other ecosystem assessment tools are summarized in Table 2.2.

The field investigation at a single assessment site (each village) was carried out by 10–15 people (including both local evaluators and researchers) spending less than one whole day (seven hours: four hours for field data collection and three hours for focus group discussion). Notably, the focus group discussion was performed only once for all the seven villages at the same time after completing field data collection of all the seven villages. That is the field investigations of all the seven villages in the participatory assessment were accomplished within four days. This significantly showed that the participatory assessment tool had time-saving efficiency and required low labour demand.

In terms of affordability, it was necessary to prepare only lunch and water for all the local evaluators on each day. There was no need for paying labour cost to them. This is a usual practice for any volunteered activities at this site.

This participatory assessment tool was designed to fill a critical gap of the suitability to be used in a participatory approach with local people, so the author hypothesized that all the 14 selected community forest ecosystem functions (Table 3.1) required low specialist technical knowledge (ecological theories) and computational skills. During a one-day field workshop, all the selected ecosystem functions could be scored by the local evaluators (based on the scoring criteria shown in Appendix 3). Only calculating ACS by using the allometric equations (see more details in Appendix 3) for 'gas regulation' was too complicated for the local evaluators. Introducing young people in the participatory assessment could accomplish this task with less assistance from the researchers.

Based on the 33 community forest ecosystem functions (Table 2.1), only 14 items covering all five main ecosystem functions were selected in this participatory assessment tool. In fact, ‘ornamental resources’ was selected as another item of the production functions, and several orchid species were found during the field surveys. Unfortunately, there were no ones who could identify these orchid species even their vernacular names. Consequently, the ‘ornamental resources’ was finally removed from the tool. The results suggested that engagement of local expertise is necessary in the participatory assessment.

To deal with ‘time-saving efficiency’ in the participatory assessment, some of the community forest ecosystem functions, especially the ones in information and carrier categories, were difficult to be quantitatively assessed. For example, we need at least 5–10 years for monitoring the changes of community forest areas (the assessment of possible reforestation in the future). For this reason, the qualitative assessment was applied in some community forest ecosystem functions.

According to the above-mentioned characteristics of the participatory assessment tools, especially ‘high’ time-saving efficiency, but ‘low’ labour demand and cost, and requirement of specialist technical knowledge and computational skills, the results proved that the tool was suitable to be used with the local people in the participatory assessment of their community forest ecosystem status.

5.4 Benefits of participatory assessment to the local evaluators

5.4.1 Broadening the perceptions on the community forest ecosystem functions

According to one-day field workshop, about 70% of the participants stated that the participatory assessment of the community forest ecosystem status in all the seven villages broadened their perceptions on the community forest ecosystem functions, not only focusing on the production functions, but also covering the other four main categories. Even for the production functions, they recognized that not only food (NTFPs) was included in this category, but there were also raw materials (timber) and medicinal resources (medicinal plants).

5.4.2 Promoting CFM planning at the subdistrict scale

Based on one-day field workshop, the local evaluators also mentioned that local people in Lainan Subdistrict (including them) usually harvest NTFPs in the community forests of their own village. They hardly visit the community forests of other villages. However, the participatory assessment gave them a chance to visit the community forests of all the seven villages during the field investigations. This promoted them to better understand the physical characteristics and conditions of all community forests in Lainan Subdistrict as fundamental information for future CFM planning at the subdistrict scale.

5.4.3 Learning the assessment practices and recognizing of the community forest degradation risks

In a single assessment site (village), each individual assessor took responsibility in data collection of at least one community forest ecosystem function. He/she turned to gather data in other ecosystem functions after finishing the participatory assessment in each village. That is the local assessors learnt the assessment practices covering several community forest ecosystem functions when finishing the participatory assessment in all the seven villages. This would promote self-assessment for long-term monitoring of their community forest ecosystem status in the future.

At the end of the field workshop, more than 80% of the assessors recognized that the Lainan's community forests, especially the lower and middle ones, are vulnerable for degradation due to the occurrence of several forest degradation risks (Table 5.1). They agreed that there are the needs to assess their community forest ecosystem status in the future in order to monitor long-term changes in the forest status. Furthermore, one of them requested the researchers to conduct more similar assessment sessions at his village with teenagers to promote the transmission of traditional knowledge to young villagers.

5.5 Dealing with the current key risks of community forest degradation

Although there were not any villages receiving 'very poor' or 'poor' in their community forest ecosystem status (Figure 5.1), these villages were still facing with several degradation risks, as shown in Table 5.1. Occurrence of wildfire and loss of the traditional knowledge were considered as the current key forest degradation risks since these two degradation risks were identified in almost all the villages (Table 5.1). This suggested that there are the needs for considering how to avoid or mitigate these two challenging issues in future CFM planning.

5.5.1 Wildfire prevention and detection

Traditionally, the strategies used for preventing wildfire at this site were firebreak establishment and fire detection patrols. Generally, firebreaks were established in late cool and dry and early warm and dry seasons (in January and February) by in-line removal of leaf litter which is a major fuel source in a deciduous forest ecosystem. During March and April, local fire patrolmen (most of them are the village leaders) took responsibility for watching for fires. However, high labour demand for the patrols in both day and night periods was required due to the large total area of the Lainan's community forests covering 431 ha (Table 4.1). To save labour demand and time consuming in the fire detection patrols, using drone (Petagon, 2019) or remote sensing (Suksabai and Nakhapakorn, 2014) is interesting to be applied at this site.

5.5.2 Maintenance of the traditional knowledge

The results from the field investigations showed that socio-economic changes and the lack of traditional knowledge documentation were the key factors relating to the loss of traditional knowledge. Based on McCarter *et al.* (2014), four approaches which are possibly used for maintaining the traditional knowledge were proposed as follows:

(i) *Integration of the locally traditional knowledge in formal education*. The inclusion of traditional knowledge and vernacular languages in schools could raise the prestige and perceived validity of the local knowledge, and it may also facilitate new structures for traditional knowledge transmission where older social networks are no longer functional (McCarter *et al*., 2014). However, according to the preliminary studies, the results showed that most of the government officers (including the small number of schoolteachers) living in Lainan Subdistrict have never come to harvest NTFPs in their community forest. Ruiz-Mallén *et al.* (2013) argued that cultural transmission of traditional knowledge generally occurs outside the formally educational system. In other words, it occurs during labour or play activities, such as harvesting NTFPs in a community forest. This confirmed that schoolteachers alone could not successfully support traditional knowledge transmission. To achieve this, integration of local key informants into the formal education is also necessary.

(ii) *Creation of the traditional knowledge databases*. Traditional knowledge of not only Lainan Subdistrict, but also other communities throughout Thailand remains poorly documented (Srithi *et al.*, 2009; Bandyopadhyay, 2018). This indicated a new challenge of future research for systematically documenting and distributing the traditional knowledge at local or regional scales.

(iii) *Securement of intellectual property*. This approach was the most widely documented approach for traditional knowledge maintenance. Many scholars sought to develop legal protections for holders of the traditional knowledge at national or regional levels in order to protect specific domains of knowledge which are considered to be at risk of exploitation (McCarter *et al*., 2014). In Thailand, the first community forest bill has recently been promulgated on 29 May 2019. It gave the right to local communities for sustainable utilization and management of their community forest. However, the substance of this bill mainly focused on 'natural resources' without mentioning the protection of traditional knowledge on these resources. This indicated that this approach was difficult to be applied for Thailand at this moment.

(iv) *Community-based maintenance of traditional knowledge*. This approach seeks to promote the transmission of traditional knowledge within communities to ensure that the knowledge is maintained inside a relevant cultural context (McCarter *et al*., 2014). Traditional knowledge is not static, but continually changing and evolving over time as cultural groups (indigenous people) innovate, borrow, and adapt their traditions to social-ecological circumstances (Dudgeon and Berkes, 2003). Therefore, among the four maintenance approaches, McCarter *et al*. (2014) proposed that the community-based traditional knowledge maintenance is the most suitable approach to deal with the problem issue of traditional knowledge loss. To achieve this, the local participation is very essential.

5.6 Degree of local participation in the participatory assessment

This study defined 'local participation' as involvement of local people in implementing the participatory assessment of community forest ecosystem status. Danielsen *et al.* (2009) proposed four different degrees of local participation, specifically for ecosystem monitoring scheme, and based on two major steps of monitoring: field data collection, and data analysis and interpretation, as shown in Figure 5.2.

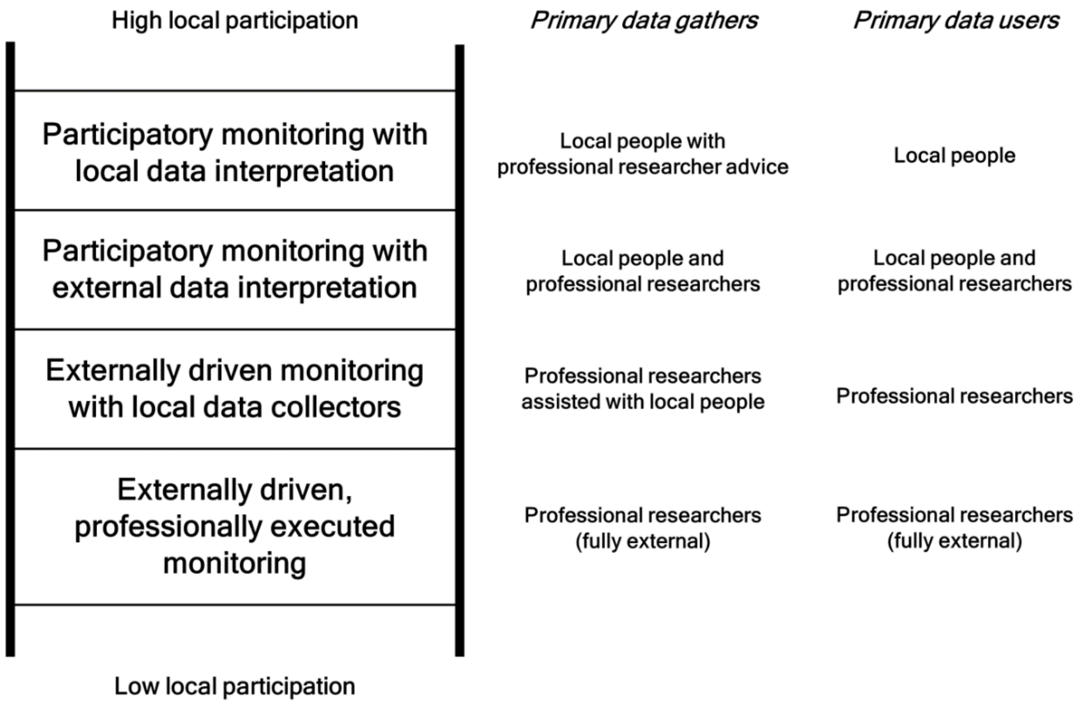


Figure 5.2: Degree of local participation in ecosystem monitoring (adapted from Danielsen *et al.*, 2009).

During field investigations, the raw data of 14 selected community forest ecosystem functions in each village were collectively gathered by both local evaluators and researchers, but the data analysis and interpretation were mainly achieved by the researchers. However, the one-day field workshop was organized after the field investigations aiming to share the ideas of data analysis and interpretation with the local evaluators. Therefore, the degree of local participation in the participatory assessment of community forest ecosystem status could be in between the rungs "participatory monitoring with external data interpretation" and "externally driven monitoring with local data collectors".

As recognized by the local evaluators for monitoring long-term changes in their community forest ecosystem status, introducing more local villagers and teenagers would increase the degree of local participation and promote self-monitoring in the future. Locally based monitoring (at high degree of the local participation) is particularly relevant in several developing countries where it can lead to rapid decisions to avoid or mitigate any threats (e.g. community forest degradation risks) and empower local communities to better manage their community forest ecosystems (Danielsen *et al*., 2009).

In fact, Danielsen *et al*. (2009) also proposed 'autonomous local monitoring' at the highest degree of local participation in ecosystem monitoring. The characteristics of this highest rung were described that the whole monitoring process―from design, to data collection, to analysis, and finally to use of data for management decisions―is carried out autonomous by local stakeholders. There is no direct involvement of external agencies, except possibly to help advocate the continued relevance of such monitoring schemes. However, the author considered that this rung could unlikely occur in actual circumstances, in particular at Lainan Subdistrict. The majority of Lainan's population consists of farmers who are usually busy managing their farmlands. That is to say it is hardly possible to invite the representatives from all the seven villages to conduct such an ecosystem assessment by themselves, especially at the whole subdistrict scale which takes much more time consuming than at the village scale. Assistance from the research team is still necessary.

5.7 Conclusion

A new tool was developed for the participatory assessment of community forest ecosystem functions and it was used with local people. The status scores among the seven community forests ranged from 233 to 322 of 500 points. Based on these status scores, only village 3 had 'good' while the other villages had 'moderate' in their community forest ecosystem status. However, all the seven community forests were still facing with several degradation risks, especially occurrence of wildfire and loss of traditional knowledge in relation to local NTFPs.

Using the participatory assessment tool with local people provided several benefits to the local communities, particularly promoting CFM planning at the subdistrict scale. The outcomes from the participatory assessment in the Lainan's community forest ecosystem status also created a shared understanding of the community forest SES between local people and the researchers. This common understanding would be used for the model design and construction as the early stage of the subsequent participatory modelling and simulation processes (CHAPTER VI) to stimulate the exchanges of knowledge, experiences, and opinions among heterogeneous local stakeholders, and facilitate the exploration of different scenarios in order to support the emergence of acceptable coordinating mechanisms and agreed upon CFM action plans.

CHAPTER VI
PARTICIPATORY MODELLING AND SIMULATION PROCESS AND RELATED COMMUNITY FOREST MANAGEMENT PLANNING

6.1 Overview of the ComMod process implemented at Lainan Subdistrict

The ComMod process implemented at the seven community forests of Lainan Subdistrict was composed of the following three main phases:

(i) preliminary diagnostic phase,

(ii) the first participatory modelling and simulation sequence, and

(iii) the second participatory modelling and simulation sequence.

Evolution of the objectives and methods and tools used in each successive phase of the ComMod process is shown in Figure 6.1.

6.1.1 Preliminary diagnostic phase

The results from the ecological field investigations based on community forest ecosystem functions as a conventional assessment (CHAPTER IV) and participatory assessment of community forest ecosystem status (CHAPTER V) were considered as the outcomes from the preliminary diagnostic phase. The key output of this phase was a shared understanding between the researchers and local stakeholders on the community forest SES and its dynamics and interactions to be used as input data to design and construct the gaming and simulation model in the subsequent phases.

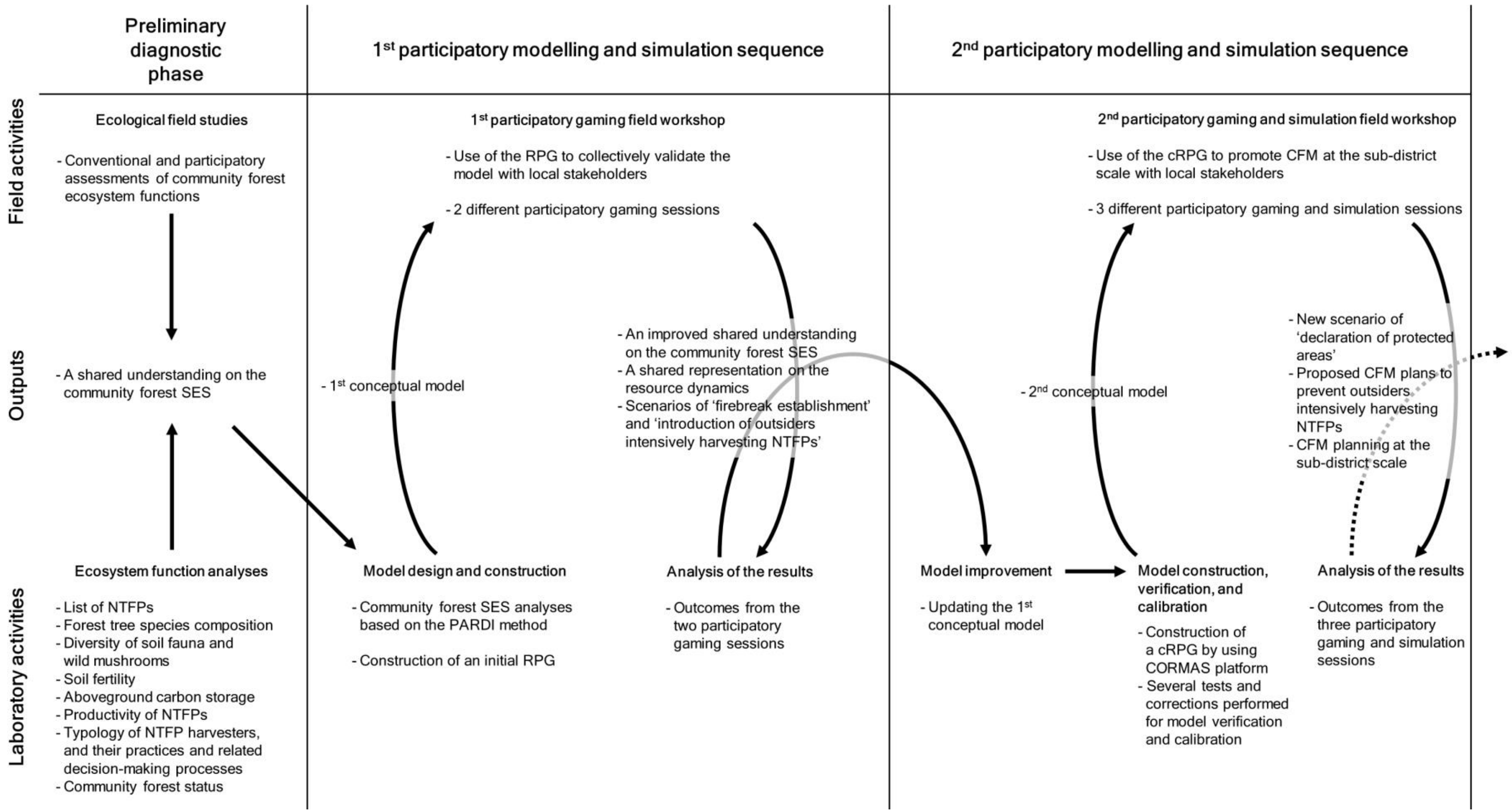


Figure 6.1: Successive phases of the ComMod process implemented at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

6.1.2 The first participatory modelling and simulation sequence

In this phase, the outputs from the diagnostic phase were used by the research team based on the PARDI method to build its own point on the issue at stake and the question to be examined with local stakeholders, and to construct the first conceptual model. The objectives of the first participatory modelling and simulation sequence were as follows:

(i) to develop a first model representing NTFP dynamics in relation to harvesters' behaviour following the first conceptual model, and

(ii) to implement this model as an initial RPG used with local stakeholders in order to validate the model with them, and explore feasible scenarios for improving the volumes of NTFPs and harvesting practices.

This first sequence was progressed through the two different participatory gaming sessions of a two-day field workshop with various types of local stakeholders. Table 6.1 summarizes the key characteristics of this first participatory gaming field workshop. Initially, the workshop was organized by separating the participants into two groups based on how much they are closely related to CFM of their village. Unexpectedly, one village headman joined the workshop with the majority of local villagers making the difficulty to elicit the viewpoints of local villagers due to social inequity and power asymmetry between them.

The key outputs of the first participatory modelling and simulation sequence were an initial RPG and suggestions from the participants to improve the initial RPG and its underlying conceptual model to be implemented as a cRPG in the next sequence.

Table 6.1: Key characteristics of the first participatory gaming field workshop.

Key characteristics	Day 1		Day 2	
	Session 1	**Session 2**	**Session 1**	**Session 2**
Objective(s)	- To co-validate the tool used (RPG)	- To explore and test feasible scenario(s) for sustainable management of NTFPs	- To co-validate the tool used (RPG)	- To explore and test feasible scenario(s) for sustainable management of NTFPs
Participants	- Local villagers with no administrative role in CFM - A village headman		- Village headmen - CFM committee members - SAO staff members	
Scenario(s) proposed by local stakeholders	- Business as usual	- Equity on resource sharing	- Business as usual	- Firebreak establishment to prevent damages to NTFP populations from wildfire - Introduction of outsiders intensively harvesting NTFPs*

*This scenario was proposed during the individual in-depth interview after the workshop.

6.1.3 The second participatory modelling and simulation sequence

In this phase, the first conceptual model was revised by (i) removing some of the gaming rules and feature, (ii) updating regeneration process of resources, (iii) calibrating the increased amount of resources resulting from establishing firebreaks, and (iv) inserting the scenario of "introducing outsiders intensively harvesting resources" based on the outputs receiving from the local stakeholders in the first sequence. The objectives of the second participatory modelling and simulation sequence were as follows:

(i) to develop an improved gaming and simulation tool representing the NTFP dynamics in interaction with agent behaviour based on the revised conceptual model, and

(ii) to implement this new model as a cRPG in order to explore additional scenarios in a time-efficient way, promote exchange of knowledge and experiences among local stakeholder and collaboration in CFM at the subdistrict scale.

Because of the nature and characteristics of this gaming and simulation tool, a cRPG can generate simulation results much more rapidly than a RPG. Therefore, it was implemented and used in this second sequence to save time during gaming and simulation sessions in order to allow longer discussion sessions among the local stakeholders.

This second sequence proceeded through the three different participatory gaming and simulation sessions of a one-day field workshop with village leaders, CFM committee members, and SAO staff members. The key outputs of the second participatory modelling and simulation sequence were the CoComForest cRPG and collective planning for CFM at the subdistrict scale which has never substantially occurred at this site before.

6.2 Outcomes from the first participatory modelling and simulation sequence

6.2.1 The first model conceptualization and description

The first conceptual model represented as a UML class diagram is shown in Figure 6.2 and the full description of this first model is provided in Appendix 11.

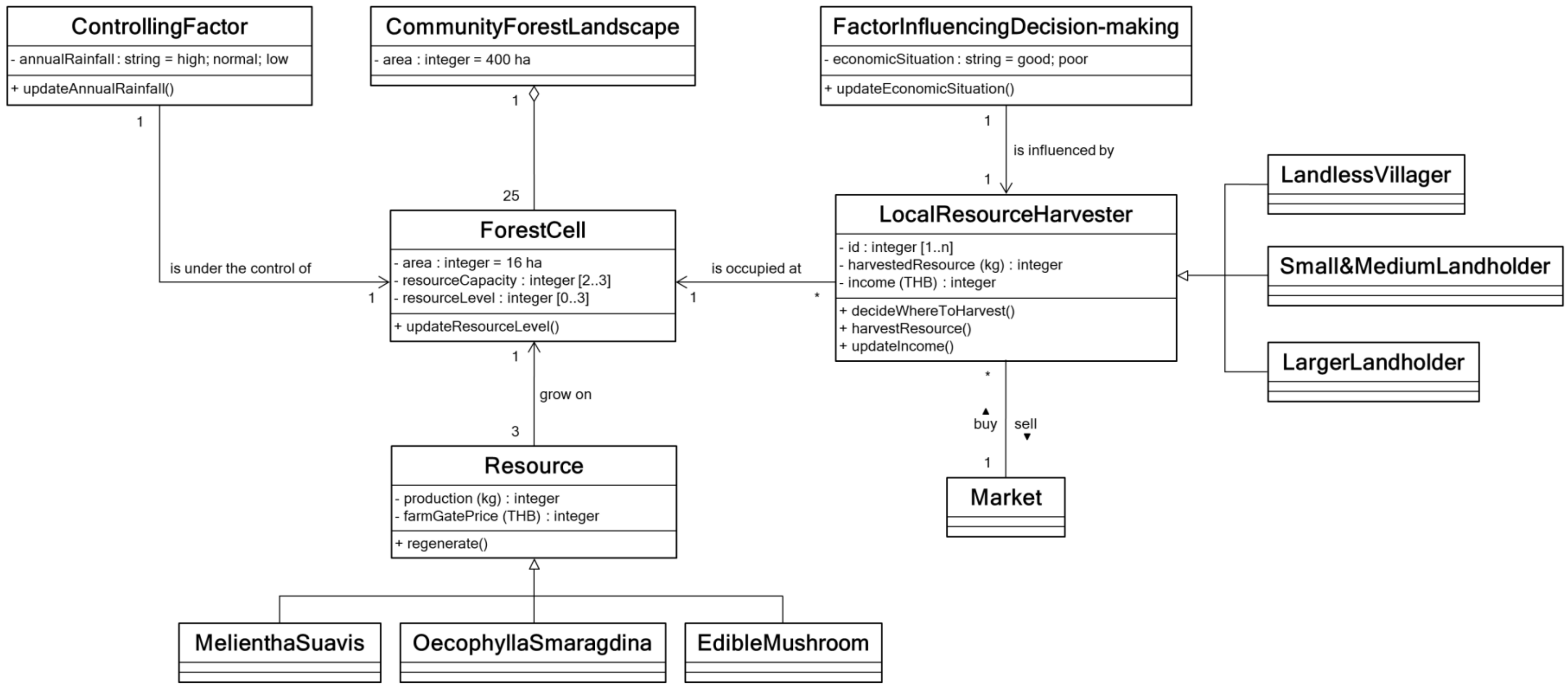
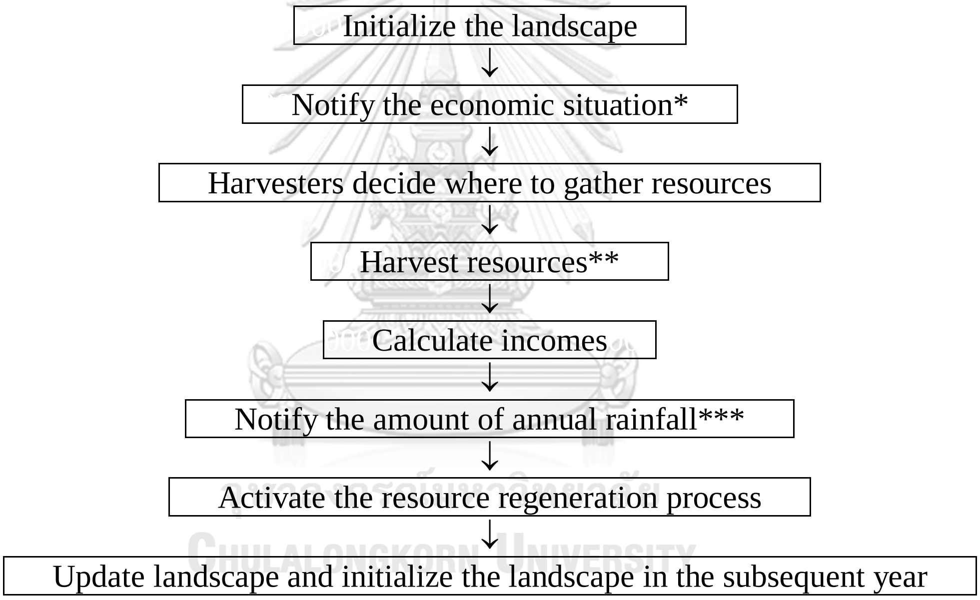


Figure 6.2: The first conceptual model as a Unified Modelling Language (UML) class diagram.

There were three main entities including (i) *community forest microhabitat* divided into 25 cells in which available resources can be found at four different levels from 0 (no resource) to 3 (high amount of resources); (ii) *local resource harvesters* who gather resources from the community forest cell, classified into three types: landless villagers, small and medium landholders, and larger landholders; and (iii) *market* (a computer-assisted entity) who buys harvested resources from the harvesters.

One round of play corresponds to one year and a gaming session is composed of at least two successive years. The scheduling of the eight successive steps in each round of play is shown in Figure 6.3.



*Starting at the beginning of the second round of the first session onwards.
**Landless villager, small and medium landholders, and larger landholders are allowed to harvest resources three times, twice, and only once in each round of play, respectively.
***The initial amount of annual rainfall of each gaming session is always defined as ‘normal’.

Figure 6.3: Scheduling of the successive steps in a year simulated by the first model implemented as an initial RPG.

To gather the resources, each harvester is limited the amount harvested in each round of play as follows:

- *M. suavis:* maximum 30 kg/harvester/round
- *O. smaragdina*'s queen brood: maximum 90 kg/harvester/round
- Edible mushrooms: maximum 30 kg/harvester/round

These harvested resource quantities are doubled for the small and medium landholders, and tripled for the landless villager due to the different number of times allowed them gathering the resources in the landscape in each round of play. At the village level, the amount of available resources in the community forests of each village is different, so the cumulated amount of resources gathered by all harvesters from the same village is also limited, as shown in Table 6.2.

Table 6.2: Collective amount of resources allowed to be gathered in each round of play.

Type of resources	Maximum cumulated amount of harvested resources in each village (kg/village/round)						
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**
Melientha suavis	120	150	250	10	30	20	20
Oecophylla smaragdina's queen brood	600	2,800	200	0	0	0	0
Edible mushrooms	40	100	300	30	30	40	60

The resource regeneration process is activated based on the amount of annual rainfall. High amount of annual rainfall increases the resource level by one unit, whereas low amount of annual rainfall decreases the resource level by one unit. The resource level does not change when the amount of annual rainfall is normal, as shown in Figure 6.4.

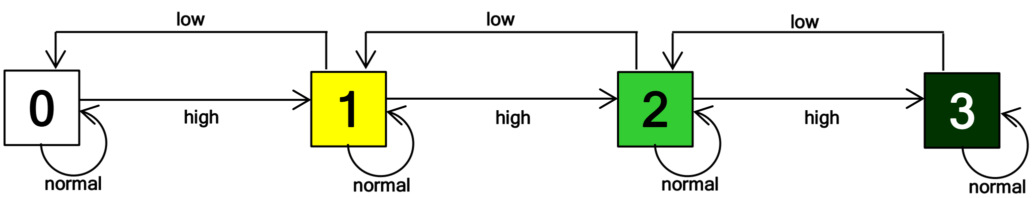


Figure 6.4: State-transition diagram of the resource level dynamics according to the amount of annual rainfall.

6.2.2 Co-validation of the RPG with local stakeholders in the first gaming session

At the end of the first round of the first session of the first day, the players requested that the amount of harvested resources should not be limited (for both individual and village levels) as there were no such limitations in actual circumstances. Therefore, the rules for limiting the amount of harvested resources were removed since the second round of the first session and this remain being applied throughout the whole second session of the first day, and also all sessions of the second day. The location of all players in each round of the first session of the first day is shown in Figure 6.5.

As an initial understanding on the resource dynamics, high amount of annual rainfall was activated at the end of the first round of the first session of the first day leading to increasing amount of resource (and its level) in almost all cells of the landscape as the initial stage of the second session (Figure 6.5b). The amount of resources in few of them did not increase as the resource level of those cells had already been at the maximum level (see more details in Figure A.2; Appendix 11).

At the end of the second round of the first session of the first day, low amount of annual rainfall was activated and decreased amount of resource in all cells of the landscape. This was the initial stage of the third session. However, the players, in particular the landless villager, strongly argued that any cells marked by double asterisks (**), as shown in Figure 6.5c should not be empty because they believed that any areas in the community forests in which the resources was initially found still has potential in providing the resources in the subsequent years. Consequently, resources were added to all the empty (white) cells in the landscape by the amount equated with the resource level 1.

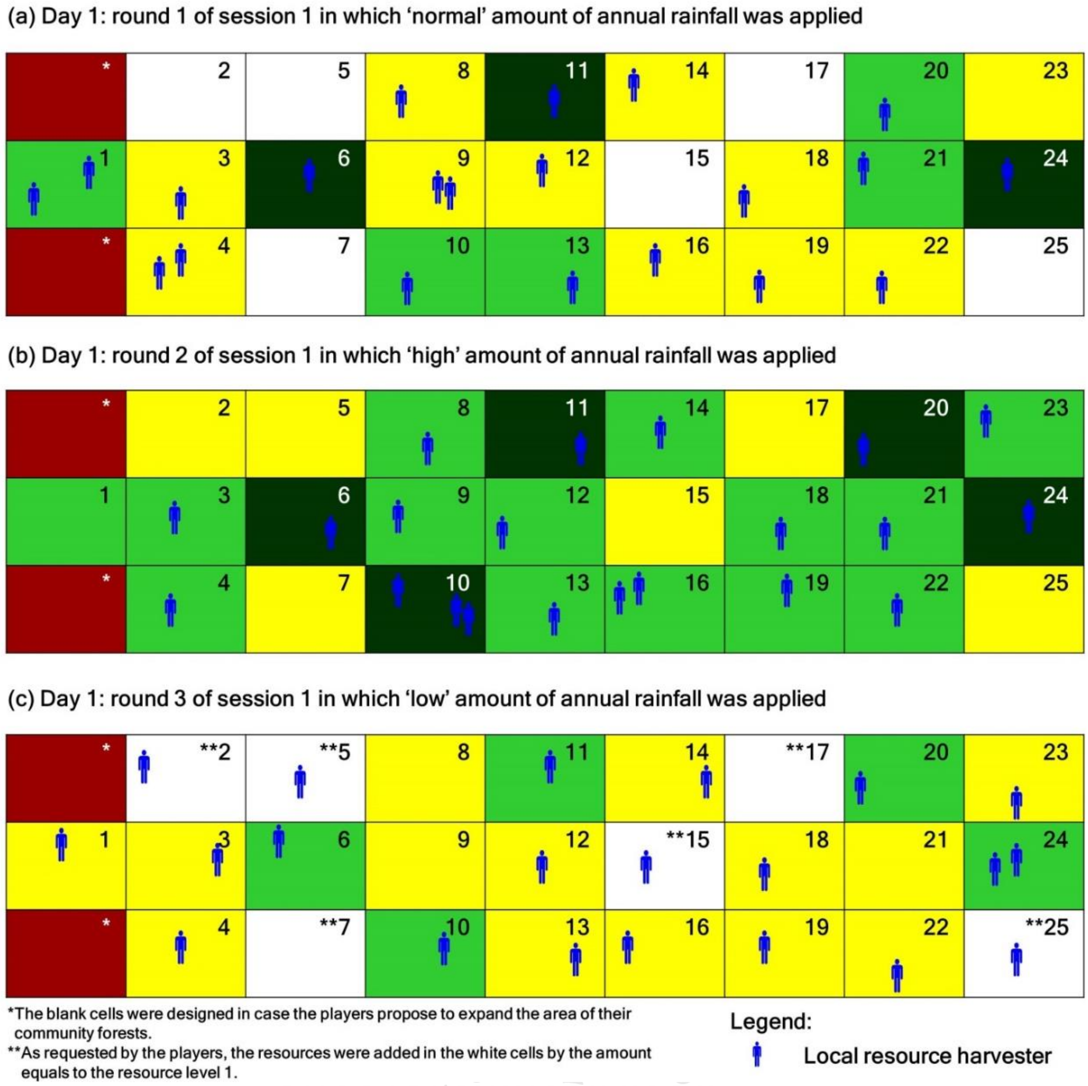


Figure 6.5: Location of all the local resource harvesters from the three rounds of the first gaming session of the first day.

6.2.3 Simulation of a scenario proposed by the participants in the second gaming session

In the first gaming session of both the first and second days, several players mentioned that the amount of harvested resources were lower than their needs. Even few of them, especially the ones harvesting resources in last sequences of each round, could not even harvest the resources because there were no resources remained in the landscape. Consequently, a short plenary discussion among the players was carried out to find out the solution to avoid such inequity on resource sharing. The proposed option was then tested through the RPG in the subsequent gaming session.

Accidentally, there was a village headman participating in the workshop of the first day. This village headman tried to enforce equity on resource sharing to every player through the successive two rounds of the second gaming session. However, his attempt was not successful because some of the players, particularly the village headman himself, still could not harvest one or two (from all three) kinds of resources in both two rounds of play. Furthermore, several players mentioned during the individual in-depth interview that this proposed scenario could not be implemented in practice as there is no such a controller on resource sharing in reality.

On the second day, the players collectively proposed an option of "firebreak establishment" to prevent damages to NTFP populations from wildfire. In other words, they proposed a scenario to improve the quantity of resources. Figure 6.6 displays the location of firebreak establishment and the players in the second gaming session. The boundaries for establishing firebreaks were collectively decided by the players based on how many laborers there were in the actual situation.

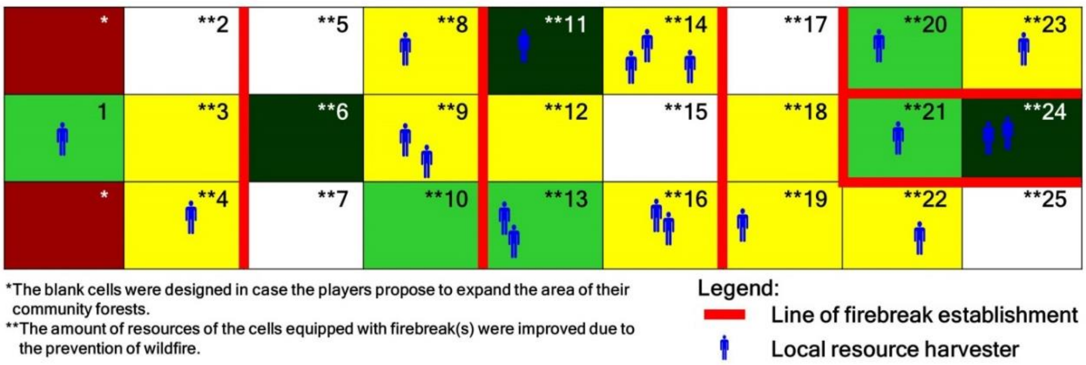


Figure 6.6: Location of all the local resource harvesters in the second gaming session of the second day in which firebreaks established.

In this second gaming session of the second day, after the firebreaks were established in the landscape, the amount of resources in any cells equipped with a firebreak at least one side (marked as double asterisk [**], as shown in Figure 6.6) was increased based on the players' past experiences. This step took much time consuming as the players needed to discuss together to find agreement on how much amount of resources need to be added to those cells. Consequently, only one round of play was conducted in the second session of the second day.

6.2.4 Players' decision-making in the gaming sessions compared to actual circumstances

Based on the initial understanding of the researchers, the author hypothesized that decision-making of harvesters on gathering NTFP in their community forests is influenced by the economic situations. Therefore, the two different economic situations were examined during the first gaming session of the first day. The 'good' (low expenses in the household with prize from winning the lottery) and 'poor' (high expenses in the household with debts) economic situations were applied in the second and the third rounds of play, respectively. The average harvested resources and income per player at the end of each round of the first session of the first day are displayed in Table 6.3.

In the third round of the first session of the first day in which 'poor' economic situations were applied, the researchers hypothesized that 'poor' economics situations would stimulate the players gather more resources from the landscape. However, the average harvested resources per player in both groups of small and medium landholders, and larger landholders decreased by more than 40%, but they were stable in the group of landless villager when comparing to the second round (Table 6.3). Based on the individual in-depth interview, the players explained that the declining amount of harvested resources in the third round resulted from lower availability of the resources in the landscape (activated by the low amount of annual rainfall) more than the 'poor' economic situations. In other words, the different economic situations did not significantly influence their decision-making on gathering resources in the community forests. Therefore, the economic situation parameter/variable was removed since the second session of the first day.

In the first session of both days, at least 10% of all the players did not harvest *O. smaragdina*'s queen brood as they have never harvested this kind of resource in actual circumstances. This confirmed that the players' decision-making to harvest the resources in the gaming sessions was based on their actual behaviour (Daré, 2005).

Table 6.3: Average harvested resources (kg/round/player) and income (kTHB/round/player) at the end of each round of the first gaming session of the first day, in which different economic situations were applied, and classified into each type of local resource harvesters.

Type of local resource harvesters	**No. of players**	**Round 1 of session 1**		**Round 2 of session 1 with 'good' economic situation**		**Round 3 of session 1 with 'poor' economic situation**	
		Average harvested resources (kg/round/player)	**Average income per player (kTHB/round/player)**	**Average harvested resources (kg/round/player)**	**Average income per player (kTHB/round/player)**	**Average harvested resources (kg/round/player)**	**Average income per player (kTHB/round/player)**
Landless villager	1	320	82	140	30	140	37
Small and medium landholders	5	96	24	146	38	87	23
Larger landholders	8	33	8	70	18	35	8

6.2.5 Comparison of ecological and economic indicators between the two gaming sessions

Table 6.4 recapitulated ecological (the average cumulated harvested resources per player) and economic (the average cumulated income per player) indicators of both the first and second gaming sessions.

In the second session of the first day in which "equity on resource sharing" was applied, the average cumulated harvested resources and income per player in the groups of landless villager, and small and medium landholders were lower compared to the first session. Specifically, the cumulated harvested resources and income of the landless villager in the second session were lower than the first session for more than 60% (Table 6.4a). This was the consequence from controlling the amount of harvested resources by the village headman. The results showed that the proposed scenario of "equity on resource sharing" could not improve the quantity of resources.

In the second session of the second day in which the option of "firebreak establishment" was applied, the average cumulated harvested resources and income per player in all types of local resource harvesters doubled compared to the first session, as shown in Table 6.4b. This was the results of preventing the wildfire damages to the NTFP populations by establishing firebreaks in the landscape. At the end of the second session of the second day, the players agreed that the scenario of "firebreak establishment" could increase the amount of NTFPs in the community forests.

Table 6.4: Average cumulated harvested resources (kg/player) and income (kTHB/player) at the end of each gaming session classified into each type of local resource harvesters.

(a) the first day

Type of local resource harvesters	Number of players	The first gaming session		The second gaming session	
		Average cumulated harvested resources (kg/player)	Average cumulated income (kTHB/player)	Average cumulated harvested resources (kg/player)	Average cumulated income (kTHB/player)
Landless villager	1	600	149	236	56
Small and medium landholders	5	329	86	216	58
Larger landholders	8	137	35	153	41

(b) the second day

Type of local resource harvesters	Number of players	The first gaming session		The second gaming session	
		Average cumulated harvested resources (kg/player)	Average cumulated income (kTHB/player)	Average cumulated harvested resources (kg/player)	Average cumulated income (kTHB/player)
Landless villager	1	62	11	156	29
Small and medium landholders	5	286	63	734	156
Larger landholders	8	98	22	216	46

6.2.6 Players' suggestions to improve the initial RPG

Based on the individual in-depth interview, some of the participants mentioned that the additional volumes of resources resulting from the firebreak establishment in the second gaming session of the second day were exaggerated and they needed to be re-calibrated. They also stated that the annual rainfall does not influence the regeneration process of *M. suavis* and *O. smaragdina*'s queen brood (Wimolsakcharoen *et al*., 2020). This corresponded to the results from the field investigations reported in section 4.2.3. Both of them could not found in rainy period (Figure 4.4). Additionally, some of the participants suggested that outsiders (who come from other subdistricts or even other provinces to collect NTFPs in the community forests) should be introduced into the future gaming and simulation tools. This initial RPG and its underlying model were improved based on all of these suggestions from the players in preparation for the subsequent participatory modelling and simulation sequence to explore additional scenarios, and promote collaboration in CFM at the subdistrict scale.

6.3 Outcomes from the second participatory modelling and simulation sequence

6.3.1 CoComForest model reconceptualization and description

The name of this model is 'CoComForest' standing for Collaborative COMmunity FOREST management and its formal conceptual model is represented as a UML class diagram in Figure 6.7. The full description of this CoComForest model is provided by Appendix 12.

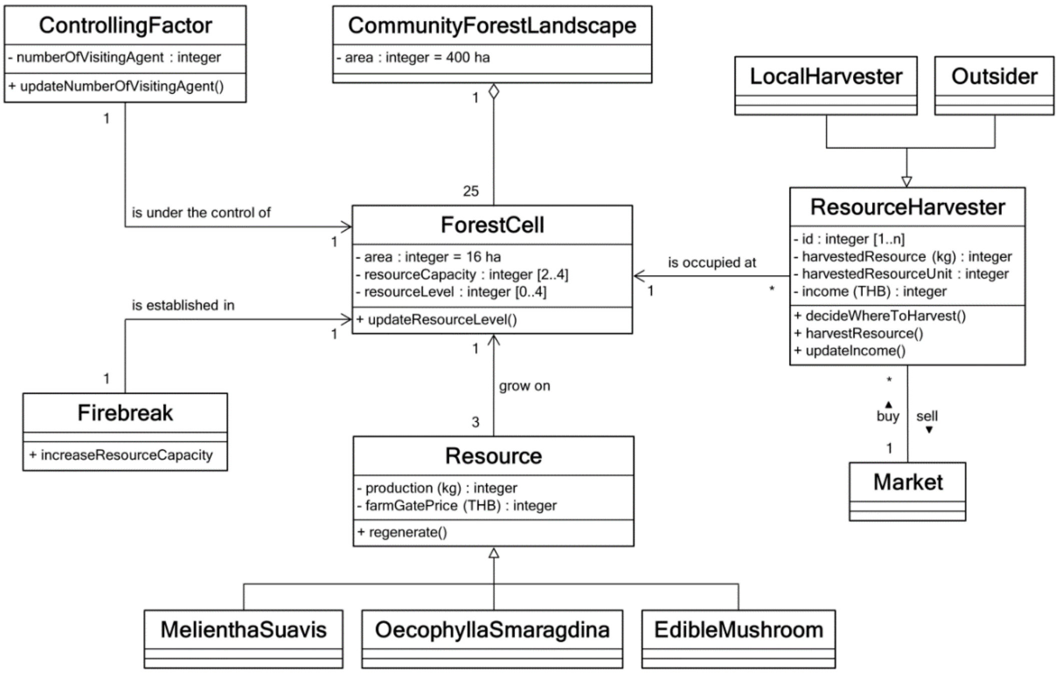
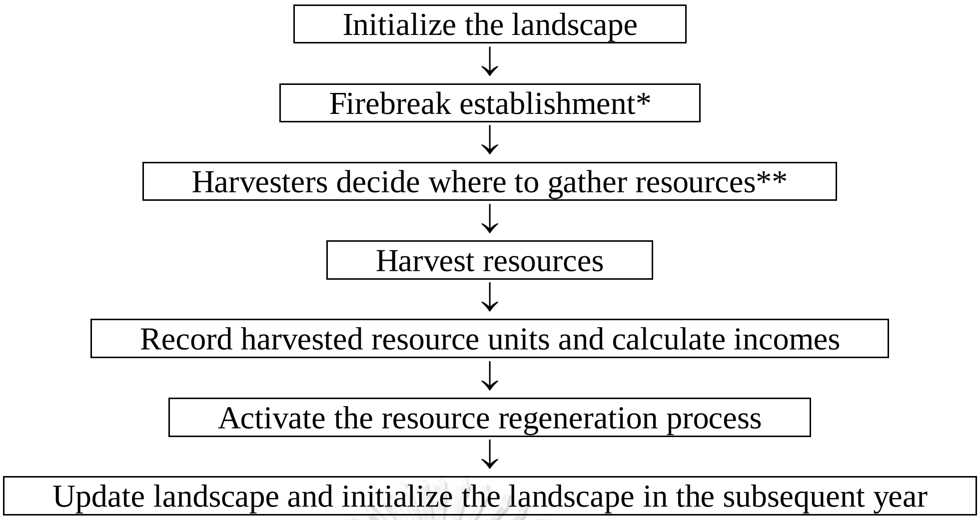


Figure 6.7: The CoComForest conceptual model as a Unified Modelling Language (UML) class diagram.

There were four main entities including (i) *community forest microhabitat* divided into 25 cells in which available resources can be found at five different levels from 0 (no resource) to 4 (very high amount of resources); (ii) *resource harvesters* who gather resources from the community forest cell, classified into two main types: local harvesters and outsiders; (iii) *market* (a computer-assisted entity) who buys harvested resources from the harvesters, and (iv) *firebreak* established as an effective and low-cost way to prevent wildfire spreading and damages to the resources.

One round of play corresponds to one year and a gaming and simulation session is composed of at least three successive years. The scheduling of the seven successive steps in each round of play is shown in Figure 6.8.



*Starting at the beginning of the first round of the second session onwards.
**The decision about where outsiders gather NTFP resources was activated in the third session.

Figure 6.8: Scheduling of the successive steps in a year simulated by the CoComForest model.

A local harvester or an outsider can gather resources in only one cell in a given round of play. If several agents visit the same cell, the available resource units are randomly allocated among them.

The resource regeneration process is activated based on the total number of visiting agent on a cell. When outsiders visit a cell, its resource level decreases to zero due to their occasionally harmful harvesting practices. In the case of different local harvesters visiting the same cell, their number affects the subsequent resource level as shown in Figure 6.9 and outlined as follows:

(a) When the number of visiting local harvesters is higher than two, the resource level decreases to zero.

(b) When there are two local harvesters visiting the cell, its resource level decreases by one unit.

(c) The resource level increases when there are no visiting local harvesters, and it does not change when only one local harvester visits the cell.

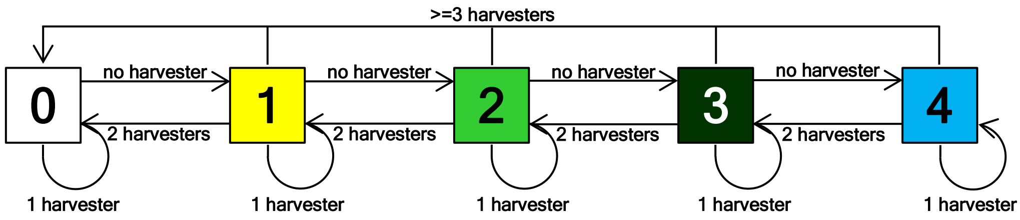


Figure 6.9: State-transition diagram of the resource level dynamics according to the number of visiting local harvesters on a given cell.

6.3.2 Co-validation of the cRPG with stakeholders in the first gaming and simulation session

At the beginning (rounds 1 and 2) of the first session, the participants were briefed about the spatial features of the grid, especially the signification of the four different colors representing the resource level of each cell. Most of the other model functionalities, such as the amount of harvested resources, the income obtained from selling harvested resources, the resource regeneration process influenced by the number of visiting agents, etc., as well as the scheduling of a round of play, were considered by the players to be similar to what they experience in their actual harvester life. At the end of the first session, no requests to change the model features or functionalities were received from the participants. This is because this cRPG was developed as an *in silico* version of the initial RPG previously used and co-validated with local stakeholders. Consequently, the same model was used in the subsequent second and third sessions.

6.3.3 Simulation of scenarios proposed by the participants

6.3.3.1 Firebreak establishment and declaration of protected areas in the second gaming and simulation session

At the beginning of the second session, the participants agreed to establish firebreaks (for preventing damages to NTFP populations from wildfire) in three different cells of the landscape (Figure 6.10a). Two of them were created on resource-rich cells (resource level ≥ 2) and the last one on a resource-poor cell. Most players believed that firebreaks should be established in resource-abundant areas to maintain a high level of resources in the forests. But a few of them thought that firebreaks should be created in degraded areas to rehabilitate them. The players agreed to maintain the firebreaks at the same location throughout the whole session as this is their practice in actual circumstances.

Additionally, one SAO staff member asked to declare protected areas in the landscape where the players were not allowed to harvest resources. In rounds 1 and 2, the players agreed to declare protected areas in the cells equipped with firebreaks (Figure 6.10a and b). But in round 3, a player (not a particularly influential one) proposed to locate the protected areas in contiguous resource-rich cells to boost the resource availability, and consequently two contiguous resource-level-2-cells were declared as protected in this final round of the session (Figure 6.10c).

During the first two rounds, one player broke the rule by harvesting resources in a protected area in each round (as shown in Figure 6.10a and b) and disturbed the resource regeneration on those cells. Consequently, before starting round 3, a penalty was introduced by the SAO staff members and researchers for violators harvesting resources in the protected cells: they would be fined 1,000 THB and all their harvest would be confiscated at the end of the round. This rule was effective as no harvester trespassed to gather resources in the protected cells in this third round (Figure 6.10c).

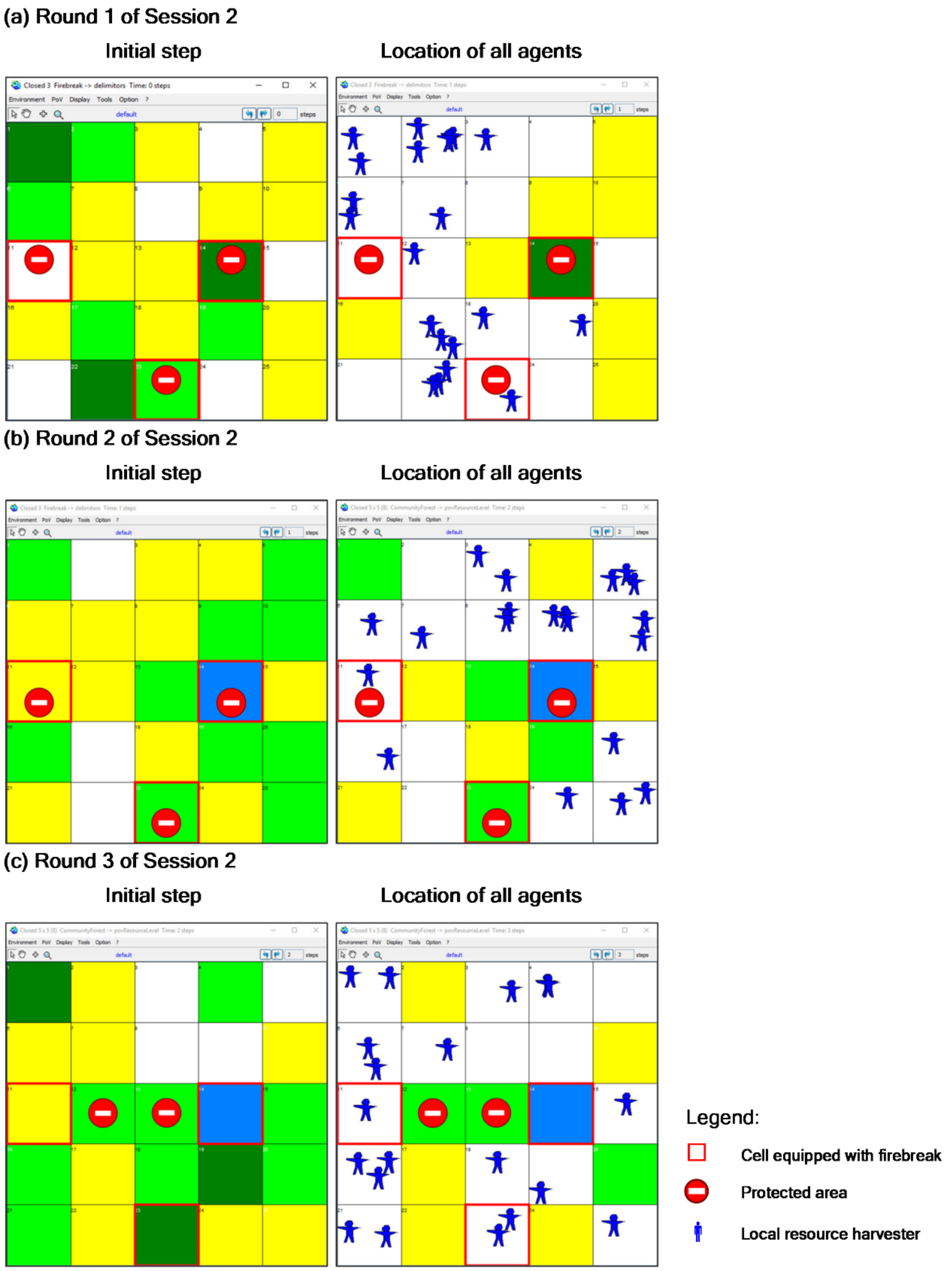


Figure 6.10: Screen captures from the three rounds of the second gaming and simulation session in which firebreaks were established and protected areas were declared.

6.3.3.2 Introduction of outsiders intensively harvesting NTFPs in the third gaming and simulation session

The firebreaks and protected areas options remained in place in this third session. But, as proposed by the local stakeholders when the initial RPG was used with them, the occurrence of outsiders intensively harvesting NTFPs was a scenario simulated and assessed in this session. Three outsiders were played by the SAO staff members. In the first round, firebreaks were established in three contiguous cells and two adjacent contiguous cells were selected as protected areas (Figure 6.11a). While the reasons behind the players' decision to select this option were not clearly expressed, this choice looks like an implementation of the island biogeography theory. This theory assumes that one large conserved area has a higher species diversity, loses species more slowly, and better preserves the full range of successional communities and patch dynamics within ecosystems compared with several fragmented and smaller conserved areas (Laurance, 2008). The firebreaks remained at the same location as in the second session throughout the following session, but in the second round, the players agreed to move the two protected cells to another two contiguous cells lacking resources at the top of the grid to rehabilitate this degraded area (Figure 6.11b).

At the end of the final round of the third session, only two green (level 2) resource-rich cells were left (Figure 6.11c), while there were four resource-rich cells, including one level 4 (blue) cell and three level 2 (green) cells, at the end of the final round of the second session in the absence of outsiders (Figure 6.10c). As expected and similar to the local stakeholders' observations, this illustrated the negative impact of the outsiders' intensive harvesting practices on the dynamics of resources in the landscape. But the final amount of resources could have been lower because the outsiders (played by the local SAO staff members) did not visit the protected cells throughout the whole third session (Figure 6.11). It can be assumed that actual intruders would visit the protected areas as well to maximize the amount of NTFPs harvested per trip to compensate for their higher transport costs and longer travelling times (Wimolsakcharoen *et al.*, 2020).

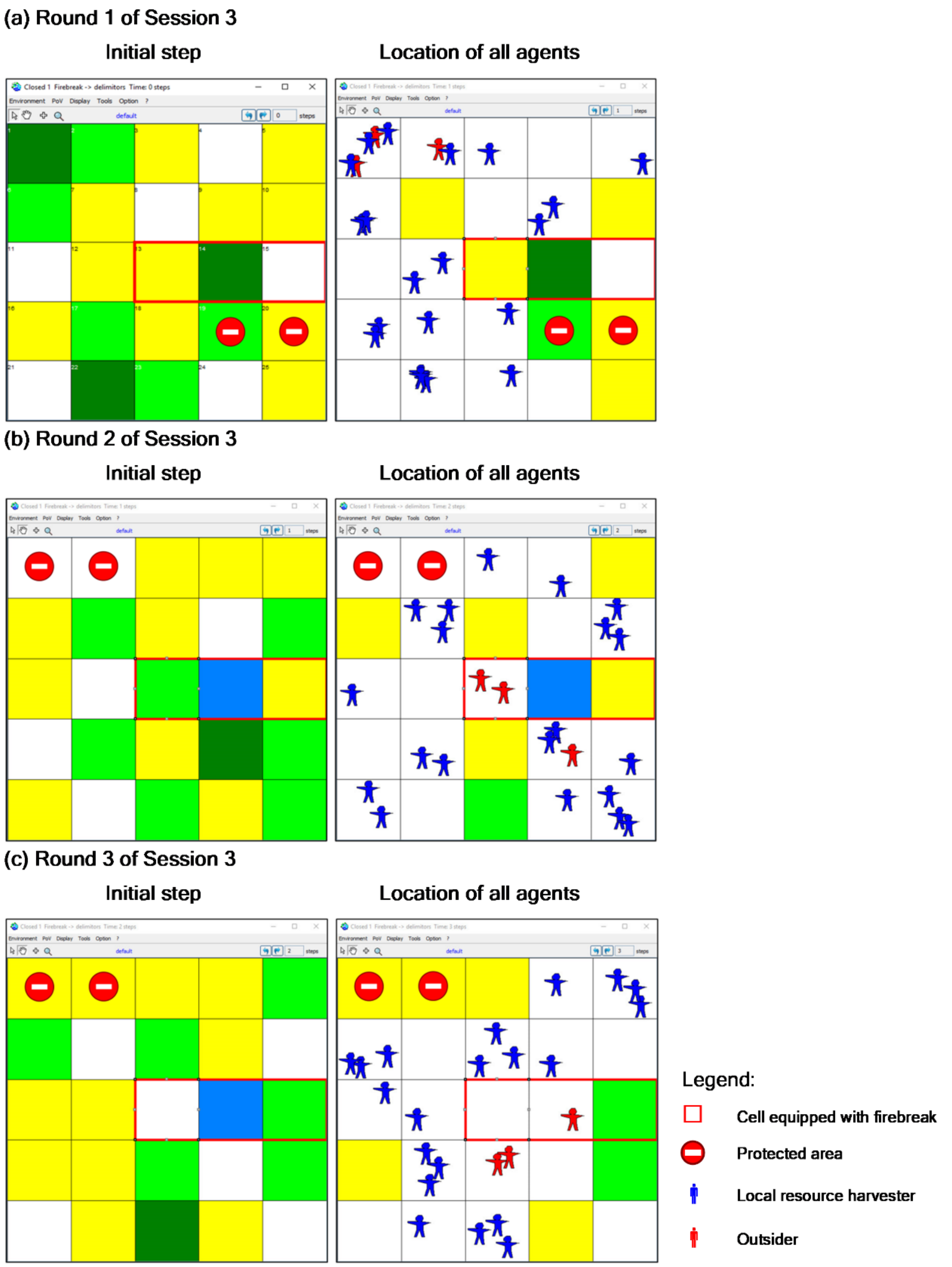


Figure 6.11: Screen captures from the successive rounds of the third gaming and simulation session in which outsiders harvested resources on the landscape.

6.3.4 Comparison of the ecological and economic indicators among the three gaming and simulation sessions

The data on the ecological (the average cumulated resource units harvested per harvester and the amount of remaining resource units in the landscape at the end of each session) and economic (the average cumulated income per harvester) indicators are provided in Table 6.5. In the second session, the average income per harvester and the remaining resource units at the end of the session were higher compared to the first session (Table 6.5). This was a consequence of the players' collective agreement to improve the availability of resources by preventing wildfire damages and rehabilitating the forest landscape through protected areas. In the third session with outsiders intensively harvesting NTFPs, the values of all indicators decreased compared to the previous two sessions (Table 6.5). The average cumulated income per harvester dropped by 34%, and the amount of remaining resources at the end of the session decreased by 40% compared to the second session following the intensive harvesting practices of the outsiders, which accelerated the depletion of resources in the landscape.

Table 6.5: Average cumulated resource units harvested (units/harvester/session), income (kTHB/harvester/session), and amount of remaining resource units in the landscape at the end of each session (units).

Gaming and simulation session (S)	Average cumulated resource units harvested (units/harvester/session)	Average cumulated income (kTHB/harvester/session)	Amount of remaining resource units in the landscape at the end of each session (units)
S1	3	38.5	10
S2	3	39.0	15
S3	2	25.9	9

6.3.5 Players' decision-making in the simulation sessions compared to actual circumstances

Table 6.6a recapitulates the behaviour of local harvesters when selecting the location of their harvest in each round of play. In the first round of the first session, most players tried to harvest as much resources as possible by visiting resource-rich cells, especially resource level 3 (Table 6.6a). After noticing that the resource level of those cells would decrease rapidly if several harvesters visited them, the number of players selecting those cells decreased in the subsequent two rounds of the first session, as well as in the subsequent two sessions. In the second session which collective decisions among the players were allowed to avoid their visiting at the same cell, a higher number of players harvested resources from cells with a low resource level (1) compared to the first session (Table 6.6a). This group of players explained that, in reality, their households only needed a small amount of resources for self-consumption as they managed relatively large farms. This illustrates the fact that the decision-making of players in these simulated situation sessions mimicked their real life strategy and practices.

Table 6.6b recapitulates the behaviour of the outsiders in each round of play of the third session. Because their strategy is to maximize the amount of harvested resources, these outsiders visited only resource-rich cells in each round of play. In the final round, one of them decided to harvest resources in the maximum resource level (4, blue cell) equipped with a firebreak. This illustrates the practices of these intruders, guided by a very short-term interest and a lack of attention to the collective improvement of resource management at the landscape level.

Table 6.6: Number of resource harvesters located on the cells and the initial number of cells in each resource level of each round of play: (a) local harvesters only, and (b) outsiders.

(a)

Round of play (Y) of each gaming and simulation session (S)	Number of local harvesters located on the cells and initial number of cells (in bracket) in each resource level (RL) in each round of play				
	RL 0	**RL 1**	**RL 2**	**RL 3**	**RL 4**
S1Y1	0 (6)	1 (11)	6 (5)	13 (3)	n/a
S1Y2	1 (4)	1 (7)	11 (12)	7 (2)	n/a
S1Y3	1 (4)	3 (5)	13 (15)	3 (1)	n/a
S2Y1	0 (6)	4 (11)	11 (5)	5 (3)	0 (0)
S2Y2	0 (3)	8 (11)	12 (10)	0 (0)	0 (1)
S2Y3	0 (4)	6 (9)	9 (8)	5 (3)	0 (1)
S3Y1	0 (6)	9 (11)	5 (5)	6 (3)	0 (0)
S3Y2	0 (6)	6 (10)	12 (7)	2 (1)	0 (1)
S3Y3	0 (6)	8 (11)	9 (6)	3 (1)	0 (1)

(b)

Round of play (Y) of each gaming and simulation session (S)	Number of local harvesters located on the cells and initial number of cells (in bracket) in each resource level (RL) in each round of play				
	RL 0	**RL 1**	**RL 2**	**RL 3**	**RL 4**
S3Y1	0 (6)	0 (11)	1 (5)	2 (3)	0 (0)
S3Y2	0 (6)	0 (10)	*2 (7)	1 (1)	0 (1)
S3Y3	0 (6)	0 (11)	2 (6)	0 (1)	*1 (1)

*Outsiders harvesting resources on the cell equipped with a firebreak.

6.3.6 Players' learning from the participatory gaming and simulation sessions

6.3.6.1 Individual learning

In the first session, a player decided to harvest resources in the same cell throughout the three rounds. This cell had an initial resource level of 3, but no resources were available in the second and third rounds. The player thought that an area with an initially high resource level would provide enough resources every year to meet his needs, but after the workshop he was able to explain how too many resource harvesters selecting the same spot influenced the decline of the resources in subsequent years even in initially resource-abundant areas.

6.3.6.2 Collective learning leading to the adaptation of resource management

More than 80% of the participants agreed that there was a high harvesting pressure in the third session due to the introduction of outsiders. The results from this session supported the analysis of the CFM problems created by the unsustainable harvesting practices of outsiders (as presented in section 4.5.5), and stimulated a debate about the options available to prevent intruders in the local community forests. Management options were proposed by the participants during the debriefing phase, such as:

(i) Collectively observe who are the outsiders and where do they come from in order to officially inform the authorities of their villages that they are not permitted to harvest NTFPs in Lainan's community forests.

(ii) Establish rules and regulations for CFM at the subdistrict scale and officially announce them to the public by posting them at the edge of each community forest, particularly the ones located along the rural roads.

To enforce the CFM rules and regulations and to translate these CFM strategies into actual collective action, most of the participants agreed on the necessity to set up a new committee for CFM at the subdistrict scale. Several village leaders also requested to organize additional gaming and simulation sessions in their villages, particularly with young villagers (less than 18 y old) to boost their future collaboration in CFM at the subdistrict scale.

6.3.7 Factors correlated to social learning

Herrero *et al.* (2019) proposed three factors that had a strong correlation with social learning generated by transdisciplinary research processes, particularly in the field of INRM as follows: (i) clarification of the normative background, (ii) openness in the co-construction mode, and (iii) balancing distribution of power (resources/powerful stakeholders).

(i) *Clarification of the normative background:* rendering the normative background explicit aims to avoid misconceptions of the participatory modelling and simulation process by the concerned stakeholders. Using the symmetrical communication processes and ensuring constant transparency on the respective normative agendas is fundamental to establishing the necessary trustful relationships and the acknowledged legitimacy among the stakeholders because they are able to understand each other's perspectives and motivations. That is to say the more the goals of the participatory process are transparent/openly discussed and the more each other's perspectives/expectations related to the problem field are exchanged, the more the normative background is explicitly clarified.

(ii) *Openness in the co-construction mode:* co-constructing the definition of the SES problem, situation, and framing the research questions by the researchers and heterogonous concerned stakeholders should ideally widen the variety of knowledge inputs and the spectrum of views allowing the problem to be identified in its SES complexity. In other words, the more methodology for collaboration and participatory tools allowed the heterogonous stakeholders to engage framing of the research questions, the scientific research methods and the objectives, and the selection of the stakeholders, the more participatory process is considered as open to the co-construct mode.

(iii) *Balancing distribution of power (resources/powerful stakeholders):* when starting the participatory modelling and simulation process, it is necessary to pay close attention to resources (time, money, human resources, and knowledge) available to all the concerned stakeholders as various asymmetries in power and resource may constitute an obstacle to social learning. That is the more power disparities and resource limitations were kept in balance by adaptation or taking advantage of the situation, the stronger the criterion.

In this case study, the researchers clarified their goal to promote collaborative CFM at the subdistrict scale to the local stakeholders since the beginning of the research project. This transparent objective was necessary for trustful interactions among all the participants. Several methods and tools, including cRPG, were used to promote dialogue and open discussions for the local stakeholders to better understand each other's viewpoints and motivations on the collective CFM problems.

The methods and tools of this research were initially selected by the research team, but a co-construction mode was activated as soon as the beginning of the participatory modelling and simulation process to modify the proposed tools and run simulations based on local stakeholders' requests and interests. The plenary debriefing showed that the three participatory gaming and simulation sessions not only generated a collective understanding on the current CFM problems, but also helped to clarify the collective choices for solving the CFM problems. This was visible through the proposed management options relying on ways to prevent intruders from harvesting NTFPs, and the foundation of a new committee for CFM at the subdistrict scale. New participatory simulation sessions will focus on these two topics, and will further demonstrate the openness of the participatory process and strengthen its co-construction mode compared to the initial sequence.

According to individual in-depth interviews with the participants after the workshop, four local villagers did not understand the simulation results because of their educational backgrounds and the power asymmetry between villagers and village headmen and CFM committee. Most of Lainan's people concede that they have less knowledge and abilities in CFM than their leaders. They usually evade public participation, or keep quiet when they attend meetings with the village leaders. This perception and behaviour make those local villagers consider that the CFM issues are not their business, and so they tended to remain passive during the plenary debriefing following the gaming and simulation sessions.

An analysis of local power dynamics can help to deal with such social inequities and power asymmetries to improve stakeholder participation (Barnaud *et al.*, 2010). The selection of participants was carefully implemented during the research design to take this socio-cultural aspect into account. Initially, the organizers did not aim to alter the social distribution of power in the CFM and planned to invite only village leaders and SAO staff members to participate in this early stage of the research project. However, a few village leaders who could not join the workshop sent local villagers to replace them. This created the above-mentioned unequal degrees of participation and power asymmetries among the workshop participants.

The research team tried to activate the three factors correlated to social learning, as seen through the outcomes of this participatory gaming and simulation workshop, because their systematic combination is necessary to generate strong social learning (Herrero *et al*., 2019).

6.3.8 Use of a cRPG

Most of the (18–60 years old) working population at this site received very limited formal education, and some of them did not complete primary education. Although 12 participants joined the RPG workshop in the first participatory modelling sequence, it seemed too early to use a computer ABM (with high participant-computer interaction, but less participant-participant interaction) with them in the subsequent participatory modelling sequence. Because this phase focused on the exploration of additional CFM strategies and testing those ideas in order to find collective agreement on CFM planning at the subdistrict scale, intensive participant to participant interaction was compulsory to stimulate the exchange of viewpoints. Therefore, the CoComForest model was implemented as a cRPG to couple high participant control with an intensive participant to participant interaction (Thavikulwat, 2009).

The cRPG tool is built on the respective strengths of an autonomous computer ABM and a RPG. A computer ABM is well suited to simulate rapidly complex systems and resource dynamics in order to allow stakeholders to explore the potential consequences of various choices in collective decision-making processes. However, stakeholders may perceive it as a black box not to be trusted (Barreteau and Abrami, 2007). Whilst a RPG is a powerful tool “to open such a black box” by empowering local stakeholders to enrich the underlying model to better relate its contents to their actual situation and concern. But a RPG is rather time and labor intensive to design and use, and the experimental results of gaming sessions are difficult to reproduce due to numerous uncontrolled factors (Barreteau *et al.*, 2003b; Barreteau and Abrami, 2007).

Table 6.7 highlights the capabilities and resource requirement of the CoComForest model, used as a cRPG compared to an autonomous computer ABM and a RPG. The cRPG borrowed several strengths from a computer ABM such as a high effectiveness in spatial and temporal representations, and the capabilities to process both qualitative and quantitative parameters in a time and cost effective way, as well as to handle uncertainty. However, mainly because of time limitations, the transparency of the cRPG was not high enough for all the participants to understand the results of the gaming and simulation sessions.

Like in the case of a computer ABM, the implementation of the cRPG tool required computer resources and programing expertise to code and debug the Smalltalk object-oriented computer language, combined with the acquisition of knowledge on the community forest SES. That was very time consuming and was limiting the use of such methodology and tools to situations where these resources are available.

There have been limited applications and use of a MAS approach in CFM, especially in the tropics where deforestation and forest degradation have long been a major environmental problem (Seymour and Harris, 2019). The rather generic and simple CoComForest model and its associated cRPG tool tested in this case study could be useful to improve collaborative CFM at other sites facing similar problems.

Table 6.7: Comparison of the capabilities and resource requirements among a role-playing game (RPG), a computer-assisted role-playing game (cRPG), and a computer agent-based model (ABM).

	Desired model characteristics	RPG	cRPG (semi-automatic simulator)	ABM (fully interactive simulator)
Capability	Spatial representation	Low	High	High
	Temporal (dynamics) representation	Low	High	High
	Processing qualitative results	Medium	High	High
	Processing quantitative results	Low	High	High
	Ease of communicating results	Medium	Medium	Low/Medium
	Transparency	Medium/High	Medium/High	Low
	Ease of modification	High	Medium	Medium
	Supporting feedback loops	High	High	High
	Handling uncertainty	Medium	High	High
Resource requirement	Time and cost	Low/Medium	Medium/High	Medium/High
	Data (empirical)	Low	Medium	Low/Medium
	System knowledge (conceptual)	Medium/High	High	High
	Expertise of modelers	Medium	High	High
	Methodological expertise of stakeholders	Low	Low	Low/Medium
	Computer resources	Low	High	High

NB: A rating of 'Low' means that a tool is less able to produce outputs that have the desired capability/requires less of the resource than is a tool rated 'High' on the similar capability/resource requirement (adapted from Voinov *et al*., 2018).

6.4 Conclusion

After the first model implemented as an initial RPG was used in the first participatory gaming field workshop to co-validate the first conceptual model with local stakeholders, two scenarios were proposed by the participants in order to improve the quantity of resources in the community forests: (i), "equity on resource sharing" proposed on the first day and (ii) "firebreak establishment" proposed on the second day. However, only the scenario of "firebreak establishment" was accepted by the players as the option which can be applied in reality to improve the amount of resources in the community forests. The scenario of "introduction of outsiders intensively harvesting resources" was also suggested to be applied in future gaming and simulation tools. Additionally, several recommendations to improve the initial RPG receiving from the players were proposed as follows:

(i) removal of the rules to limit the amount of harvested resources in both individual and village levels,

(ii) removal of the economic situations, and

(iii) correction of the controlling factor influenced the resource regeneration process.

The couple of proposed scenarios ("firebreak establishment" and "introduction of outsiders intensively harvesting resources") and those recommendations were used to improve the first conceptual model and develop the new version of the model called CoComForest to be implemented as a cRPG in the second participatory modelling and simulation sequence.

The CoComForest model was constructed using the CORMAS platform and used with heterogeneous local stakeholders as a cRPG during a one-day field workshop. Three participatory gaming and simulation sessions were organized with different objectives as follows: (i) to co-validate this new model with the local stakeholders, (ii) to assess the establishment of firebreaks and the declaration of protected areas on the resource dynamics, and (iii) to evaluate the effects of outsiders intensively harvesting local NTFPs. The simulation results from the sessions stimulated most of the participants to share their viewpoints and more clearly understanding on the CFM problems, particularly the issue of outsiders' damaging practices of intensive harvest of NTFPs in the community forests. Several management options to deal with this problem were debated during the closing plenary debriefing, but still need to be presented to more local villagers and need to be translated to actual collective action.

CHAPTER VII
DISCUSSION

7.1 Evolution of the level of stakeholder participation

The ladder of citizen participation (Arnstein, 1969) can be used to explain the level of participation in INRM. However, Hurlbert and Gupta (2015) argued that Arnstein (1969)'s ladder of participation did not address the conditions under which participation may work and the conditions that determine what level of participation should be used. They proposed a new 'split ladder of participation' in which several elements including the structuring of a policy problem (a gap between a current situation and a more desirable future one, and classified into structured, moderately structured, and unstructured ones[6]), social learning, trust, information flow, and the concepts of management versus governance are taken into account. As the structuring of a policy problem is an important determinant of an appropriate mechanism of public participation (Hurlbert and Gupta, 2015), the author simplified the split ladder of participation specifically corresponding to this kind of policy problem, as shown in Figure 7.1, and assessed the policy problem in this case study as 'a moderately structured policy problem'.

[6] Based on Hurlbert and Gupta (2015), **structured problems** are problems where there is substantive agreement on norms, principles, ends, and goals surrounding the policy problem and agreement on the knowledge inherent in solving the problem. These problems are largely determined by technical/bureaucratic specialists who are guardians of the public interest. **Moderately structured problems** occur when policy makers have either some agreement on norms, principles, ends, and goals in defining a future state, or some agreement on the relevant and required knowledge inherent in solving the problem, but not agreement on both norms as well as knowledge. **Unstructured problems** are those in which uncertainty exists in respect to the values and science. They are akin to 'wicked problems' social messes, or untamed public problems. Their causes and effects are difficult to identify and model; they are intractable and elusive because they are influenced by many dynamics factors and tend to be connected to other problems.

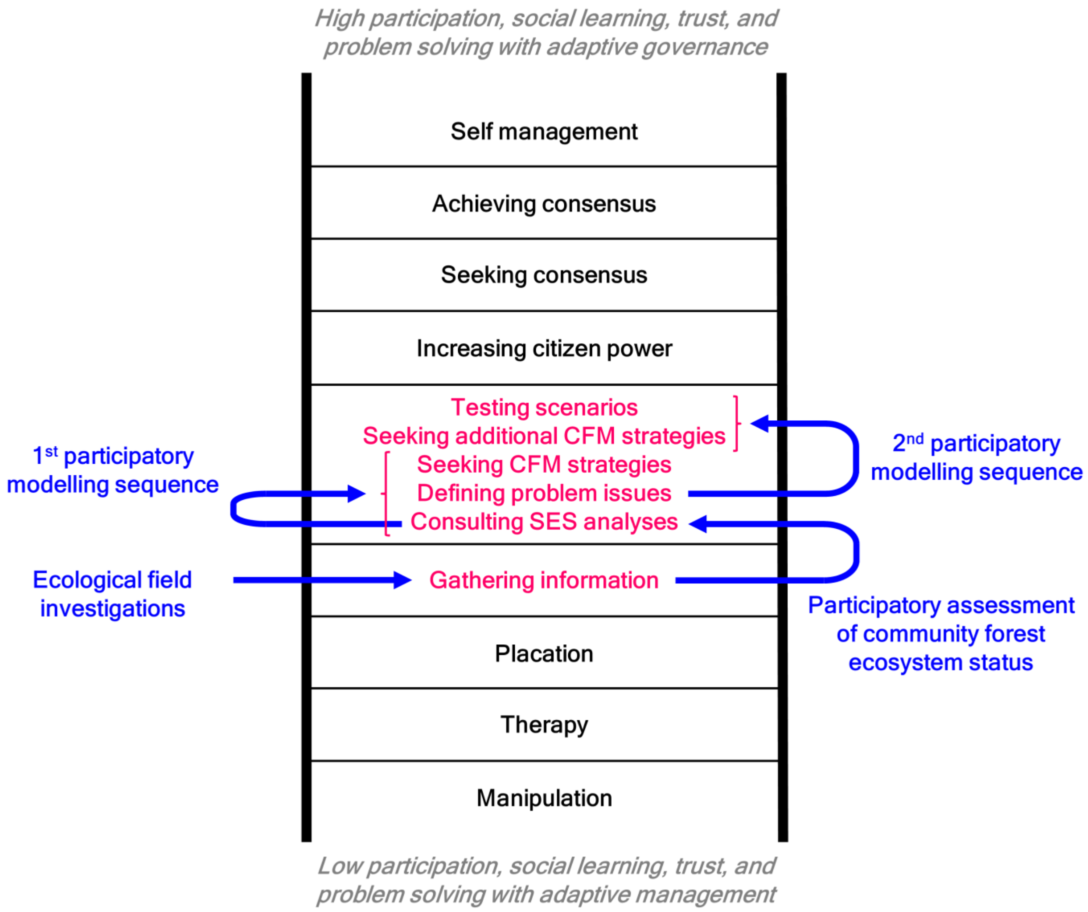


Figure 7.1: The split ladder of participation specifically corresponding to a moderately structured policy problem (adapted from Hurlbert and Gupta, 2015) and the evolution of stakeholder participation in each phase of the ComMod process implemented in this case study.

The lowest rungs of the split ladder of participation (manipulation, therapy, and placation) were identified as 'no stakeholder participation' which is closely related to a top-down management approach, while the ComMod methodology was used following a bottom-up management approach. Therefore, the evolution of stakeholder participation in the ComMod process implemented at this site started at the forth rung 'gathering information' of the ladder through the activity of ecological field investigations, as shown in Figure 7.1. At this phase of the ComMod process, only one local key informant was engaged, and actual exchanges of knowledge, experiences, and opinions between the researchers and diverse local stakeholders did not occur (Table 7.1).

Table 7.1: Number of local stakeholders, social learning and adaptive capacity, information flow, and level of stakeholder participation in each phase of the ComMod process implemented at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

Each phase of the ComMod process implemented at Lainan Subdistrict	No. of local stakeholders and new participants (in bracket) of each phase	Cumulated no. of local stakeholders	Social learning/ adaptive capacity	Information flow	Level of stakeholder participation
Ecological field investigations	1 (1)	1	n/a	One-way	Gathering information
Participatory assessment of community forest ecosystem status	23 (23)	24	- Collective learning and understanding of the community forest SES	Two-way	Consulting SES analyses
The first participatory modelling sequence	33 (21)	45	- Exchanges of knowledge, experiences, and opinions - Improved collective understating of the community forest SES - Collective understanding on the CFM practical problem situation	Two-way	Consulting SES analyses, defining problem issues, and seeking CFM strategies
The second participatory modelling sequence	21 (3)	48	- Exchanges of knowledge, experiences, and opinions - Collective agreement on CFM options at the subdistrict scale	Two-way	Seeking additional CFM strategies and testing scenarios

A small group of heterogeneous local stakeholders, including local villagers, their village leaders, CFM committee members, and SAO staff members, were invited to participate in the three subsequent phases of the ComMod process (Table 7.1). Two-way information flow between the researchers and local stakeholders was noticed since the participatory assessment of community forest ecosystem status. This made the level of stakeholder participation climb up to the next rung 'consulting SES analyses'.

Although the first participatory modelling sequence was mainly performed to promote collective understanding on the CFM practical problem and to seek CFM strategies through the use of the initial RPG, collective understanding on the community forest SES's dynamics and interactions was also improved. The NTFP regeneration was clarified by replacing the amount of annual rainfall by the number of visiting harvesters (as reported in section 6.2.6).

In the last phase of the ComMod process, a two-way flow of information was only observed between a small group of village leaders and SAO staff members, and the researchers. Even though the social learning aspects were generated by the participatory gaming and simulation sessions of the second workshop (as mentioned in section 6.3.6.2), there was still no iterative information flow among the heterogeneous stakeholders (in particular local villagers). This is one of the key elements for determining a 'high' level of stakeholder participation (Hurlbert and Gupta, 2015) starting from the rung 'increasing citizen power' (through discussion on different and diverse perspectives) of the split latter of participation (Figure 7.1). Consequently, the level of stakeholder participation in this last phase remained at the rung 'seeking additional CFM strategies' and 'testing scenarios', a level similar to the participation achieved in the previous two phases. But, additional CFM strategies were explored and a collective agreement on these CFM options at the subdistrict scale agreed upon following the analysis of the CoComForest simulation results in the second and third sessions of the second workshop.

Additional participatory gaming and simulation sessions need to be conducted by engaging more local villagers, especially teenagers to promote a more distributed iterative flow of information and to increase the level of stakeholder participation in the future. To climb up the split ladder of participation at the highest rung 'self CFM'

(Figure 7.1), it is very challenging for further sequences of the ComMod process implemented at this site in the future.

7.2 Tools used in the participatory modelling and simulation sequences

7.2.1 Model conceptualization and description

Müller *et al.* (2014) classified the prevalent types of model description (including conceptualization) into three categories as follows:

(i) *Natural language description:* presents a model in everyday language.

(ii) *Graphic:* uses particular visualization techniques to illustrate processes, structures, relationships, program flows, etc. It particularly supports understanding of qualitative properties of a model.

(iii) *Formal language:* describe a model in an abstract and self-consistent way with formal syntax and semantics that avoid ambiguity. There are several formal languages including ontology, source code, pseudo code, and mathematical description.

Table 7.2 summarizes the capabilities and purposes of use of the three model descriptions used in this study. The ODD protocol was used as a natural language model description to serve as a means of communication of the model to the local stakeholders. However, some of the Lainan's people received very limited formal education. Understanding the model through the ODD protocol by themselves may be too difficult and the researchers are still necessary for this communication. The UML was used as a formal graphic way to illustrate the model conceptualization and to support code generation. Although the UML is not used for the purpose of communicating the model with local people; some of UML diagrams could be useful to support the model description. For example, class diagram could be used to support understanding of the relationship among all entities in the model, and state transition diagram could be used to support understanding of the resource regeneration process. The CORMAS platform (based on SmallTalk object-oriented computer language) was used as a high-level programming language for code generating.

Table 7.2: Comparison of the capabilities of the three model descriptions in different purposes of use (adapted from Müller *et al.*, 2014).

Purpose of the model description used	**Capability of the model description**		
	ODD (a natural language)	**UML (a formal graphic)**	**CORMAS (a high-level programming language)**
Communication to scientists/researchers	High	High	High
Communication to local stakeholders	Medium	Low	n/a
In-depth model comprehension	High	High	High
Model design and development	High	High	Low
Code generation	Low	High	n/a

7.2.2 RPG/cRPG for adaptive CFM

The use of RPG and cRPG in the two participatory gaming and simulation field workshops facilitated (i) the involvement of local stakeholders (local villagers, their village leaders, CFM committee members, and SAO staff members), (ii) social learning (mentioned as collective understanding of the community forest SES and on the CFM issues, and collective agreement on the proposed strategies for CFM at the subdistrict scale), and (iii) the exchanges of knowledge, perceptions, experiences, and opinions among them across two (village and subdistrict) levels of social organization, as highlighted in Table 7.1. That is to say community engagement, social capital[7], capacity development, and cross-scale interactions were noticed from the implementation of both RPG and cRPG in this case study. These three characteristics or features were mentioned as key elements of adaptive management in

[7]**Social capital** is developed when stakeholders get to know each other, step-by-step negotiation/discussion through conflict, collective action, and improved exchanges of knowledge, experiences and opinions among them (Edwards *et al.*, 2019).

Edwards *et al.* (2019). This significantly showed that the local stakeholders' adaptive capacity in CFM improved following the use of RPG and cRPG in this ComMod process.

7.3 Method and methodology used in successful CFM

In the literature, various methods and methodologies were used in several successful cases of CFM. Some of them are highlighted in Table 7.3. These selected case studies were claimed their success in CFM based on the occurrence of at least one of the following eight key factors identified by Pagdee *et al.* (2006). These factors were composed of (i) property right regimes, (ii) institutional arrangements, (iii) community incentives and interests in organizing CFM, (iv) forest and community features, (v) degree of decentralization, (vi) financial and human resource support, (vii) level of participation, and (viii) technology and market influence. The first four ones were identified as a factor with strong influence on the success of CFM (Pagdee *et al.*, 2006). More recently, Onprom (2019) proposed another set of the indicators for sustainable CFM in relation to Thailand's ecological and socio-cultural context based on the former indicators developed by International Tropical Timber Organization (ITTO) and ASEAN Senior Officials on Forestry (ASOF). There were 35 indicators classified into seven main categories. Although these seven main categories corresponded to Pagdee *et al.* (2006), they were mainly focused on ecological aspects (accounting for five of all the seven main categories) rather than socio-cultural ones (accounting for only two of all the seven main categories).

Table 7.3: Comparison of method/methodology used in CFM between this study and references in the literature.

Case study and location	Method/methodology used in CFM	Support by external organization
Dry dipterocarp and mixed deciduous community forests at Lainan Subdistrict, Nan Province (This study)	Participatory modelling and simulation approach (ComMod)	Research team from Chulalongkorn University
Upland community forests managed by the three villages in Puerto Princesa City, Palawan Province, Philippines (Campo *et al.*, 2009)	Participatory modelling and simulation approach (ComMod)	Research team from CIFOR[1], Cirad[2], and University of the Philippines at Los Baños
Community forest at Kew Muang Village, Doo Pong Subdistrict, Nan Province, northern Thailand (Somsak *et al.*, 2002)	Public participation	Hug Mueang Nan Foundation
Community forest at Huai Lu Luang Village, Mae Yao Subdistrict, Chiang Rai Province, northern Thailand (Kaiser *et al.*, 2012)	Participatory land-based mapping and assessment of vegetation cover	Upland Holistic Development Project and Plant with Purpose (NGOs)
Mangrove community forest at Pa Klok Village, Pa Klok Subdistrict, Phuket Province, southern Thailand (Kongkeaw *et al.*, 2019)	Community mobilizations	World Wildlife Fund Thailand (NGO)

[1]Center for International Forestry Research.
[2]Centre de coopération internationale en recherche agronomique pour le développement.

The ComMod approach was implemented in this study as a participatory modelling and simulation methodology to support and promote local CFM at the subdistrict scale. The ComMod process exposed the heterogeneous stakeholders who are mostly unfamiliar with a MAS model, or are not used to thinking about a complex SES to addressing the concerns, objectives, and goals of CFM which are not typically found in other methods/methodologies, such as a classic oral presentation, a social survey, or an in-depth interview. Similar to Campo *et al*. (2009), the creative ways of facilitation in the two participatory gaming and simulation field workshops allowed the research team presenting the MAS models implemented as RPG and cRPG in a more acceptable and agreeable manner. The results from the participatory gaming and simulation sessions were subsequently used to support discussion and negotiation among the diverse stakeholders leading to the collective proposition of CFM strategies at the subdistrict scale. However, the limitation of participatory modelling and simulation methodology used in this study was the dependency of a research team as a facilitator and upon technology and equipment, in particular computer resources which are not readily available in the local communities.

CFM at Kew Muang Village was one of the successful CFM cases in Nan Province. It has been initiated by Phrakru Pitaknantakhun since 1972. Buddhist monks play an important role in CFM of northern (Sukkorn, 2018), northeastern (Prasert *et al.*, 2020), eastern (Sattayavongtip, 2018), and southern (Sangborisut, 2018) regions of Thailand. Moreover, Phrakru Pitaknantakhun was born at this village. Therefore, a very classic approach of public participation could be used to promote collaboration of local villagers in CFM. However, using such an approach of public participation in CFM at Lainan Subdistrict seems to be inapplicable due to the differences of socio-cultural context.

In October 1990, the first forest ordination in Nan Province was organized at Kew Muang Village with the support of Hug Mueang Nan Foundation. This Buddhist religious ritual of forest protection was based on indigenous knowledge and traditional believes and it was presented in several successful CFM cases in Thailand (Sukkorn, 2018; Sriviraj *et al.*, 2019). This ritual is very interesting to be used to promote collaboration in CFM at Lainan Subdistrict at the village scale, particularly in the upper community forests from villages 4 to 7 where the forest ordainment has not yet been organized (Table 4.1).

In the case of Huai Lu Luang Village, participatory land-based mapping with local village representatives by using global positioning system (GPS) and geographic information system (GIS) technology facilitated clear definition of community forest boundary leading to effectiveness in CFM planning and monitoring, as well as enforcement of the CFM rules and regulations. Additionally, remote sensing technology was used to assess three-year changes on community forest vegetation cover. This monitoring could be used as an overall metric to indicate long-term CFM efficacy (Kaiser *et al.*, 2012). Although the boundaries of Lainan's community forests were clearly defined (Anonymous, 2009), long-term monitoring of the community forest ecosystem status in the future is still necessary, as mentioned in section 5.6. The use of remote sensing technology seems to be applicable for monitoring gas regulation (effectiveness to mitigate global warming through carbon sequestration in aboveground biomass) and reforestation (changes of the forest areas) in the future participatory assessment of community forest ecosystem functions as it is less expensive and time-consuming compared to traditional field surveys (Kaiser *et al.*, 2012). However, only a challenge to apply this technology to the Lainan's community forests is a need of training local stakeholders to be proficient with it.

Community mobilizations were addressed in another successful CFM case of Thailand. To rehabilitate a degraded community mangrove forest ecosystem, groups and activities of conservation and natural resource management, such as mangrove reforestation and blockading shrimp farmers who were attempting to build farms in mangroves, were organized within community-based networks. At the same time, these networks were made broader by increasing cooperation with official agencies across various institutional scales (at provincial, regional, and national levels) leading to effectiveness in mangrove restoration, as well as enforcement of CFM rules and regulations (Kongkeaw *et al.*, 2019). Originally, each village of Lainan Subdistrict had its own CFM committees, as well as rules and regulations for several decades, as mentioned in sections 4.2.1 and 4.2.2. The ComMod process initiated the local stakeholders to build such a community-based network at higher institutional scale (from village to subdistrict levels). Integration of community mobilizations through expanding the CFM network across various institutional scales in the future sequences of the ComMod process would be very interesting. The following external agencies could be invited to participate in the CFM networks:

(i) *Hug Mueang Nan Foundation:* a social aggregation of groups of Buddhist monks, local villagers, and youths who live in Nan Province since 30 years ago for the purposes of environmental conservation.

(ii) *Academic institutions in Nan Province:* Rajamangala University of Technology Lanna Nan, Mahachulalongkornrajavidyalaya University Nan Buddist College, etc.

(iii) *Royal Forest Department (RFD):* CFM is one of the duties of RFD following the first Thailand Community Forest Bill enacted in May 2019, so RFD staff members (at provincial, regional, and national levels) would be very helpful to support local CFM.

Interestingly, support by external organizations including non-governmental organizations (NGOs) and academic institutions was presented in all the above-mentioned case studies at least in the early phases of the research project. In most of those cases, the external organizations played an important role as a facilitator for connecting local knowledge with scientific knowledge, sharing integrated local-scientific knowledge, building trust, bridging organizations, etc. (Kongkeaw *et al*., 2019). This significantly showed that external support is necessary for the success in CFM (Pagdee *et al*., 2006; Kaiser *et al*., 2012; Kongkeaw *et al*., 2019).

CHAPTER VIII
CONCLUSION AND PERSPECTIVES

8.1 Conclusion

Ecologically conventional and participatory assessments of the community forest ecosystem functions were performed as a preliminary diagnostic phase of the whole ComMod process implemented in this research. The results showed that almost all the seven villages had ‘moderate’ in their community forest ecosystem status and all of them were still facing with the degradation risks, particularly occurrence of wildfire and loss of traditional knowledge in regard to local NTFPs. The major output from this preliminary diagnostic phase was an integrated understanding on the community forest SES and its dynamics between local stakeholders and the researchers. It also generated interactions used as input data to build the modelling and simulation tools in the subsequent phases.

In the first participatory modelling and simulation sequence, the conceptual model was constructed and implemented as an initial RPG with local stakeholders in order to collectively validate the model, and explore feasible scenarios proposed by local stakeholders to collectively improve the quantity of NTFPs harvested and their harvesting practices. The key output from this participatory modelling and simulation sequence was two scenarios related to current major CFM problems proposed by the players: firebreak establishment to prevent the damages to resource populations from wildfire and the introduction of outsiders intensively harvesting NTFPs.

In the second participatory modelling and simulation sequence, the CoComForest cRPG was constructed and implemented based on a further improved understanding on the SES dynamics and interactions and two proposed scenarios obtained from the first participatory modelling and simulation sequence. The key outputs of this phase were several management plans to prevent NTFP harvesting of outsiders and planning of CFM at the subdistrict scale which have never been substantially occurred at this site before.

Following the use of RPG and cRPG in the ComMod process, the results showed that adaptive capacity in CFM of local stakeholders and their collaboration in CFM at the subdistrict scale were improved. However, there is still the need for translating these CFM propositions into actual collective actions on the ground. To do so, further gaming and simulation sessions and focus group discussions, with more diverse of local stakeholders, will be necessary.

8.2 Perspectives

Based on the outputs from the ComMod process implemented in this study at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand, below are suggestions to improve the participatory modelling and simulation process, its tools used, as well as propositions about further research to be performed in the future.

8.2.1 Preliminary diagnostic phase

Due to the fact that the community forest SES is continuously evolving, the ecological field investigations need to be conducted in the future for monitoring any changes of the key ecological processes and human activities, and their interactions and dynamics. However, this study clearly showed that the ecological field investigations carried out in this preliminary diagnostic phase took very much time consuming for over two successive years. In terms of time-saving, the participatory assessment of community forest ecosystem status is a very useful approach for collectively analyzing the community forest SES, but the professional researchers need to be engaged to support local accessors in field data collection. The locally based assessment with less assistance of the professional researchers will be very helpful for identifying such key changes occurring in the future.

8.2.2 Participatory modelling sequences

According to the results from the participatory gaming and simulation field workshops, it is clear that involving multiple stakeholders, in particular local villagers with marginalized or silenced voices, into the process is a challenging task due to their personal perception that CFM is not their business, and their usual passive behaviour when attending public meetings with their leaders (unequal relationships). To empower those marginated ones, separating gaming and simulation sessions with only local villagers (without their leaders and SAO staff members) would be necessary in order to elicit those local villagers' perceptions and stimulate their expression (Barnaud and Van Paassen, 2013).

8.2.3 Future sequences of the research project

In future sequences of the research project, the author intends to invite younger villagers involving the process and use the CoComForest model as a RPG in which the players will be able to calculate the harvested resources and update the landscape accordingly by themselves to replace the computer data processing of the cRPG tool. This choice of a RPG as a key simulation tool seems to be a more suitable methodological option in order to promote intensive interactions and cross-generational knowledge exchange among the participants leading to traditional knowledge transfer across generations, as well as to make local stakeholders more autonomous in the use of simulation tools without the presence of the research team in the future.

In parallel, at the subdistrict scale, there is still a need to transform the CFM plans dealing with NTFP harvesting by outsiders and CFM planning at the subdistrict scale proposed at the end of the second participatory gaming and simulation field workshop into actual collective action on the ground. To do so, further focus group discussions need to be conducted with village leaders, CFM committee members, and SAO staff members.

Finally, to promote 'self CFM' as a new challenge mentioned at the end of section 7.1, the locally based assessment for monitoring any future changes or even transfomation of the Lainan's community forest SES needs to be carried out in future sequences of the ComMod process. Currently, the local stakeholders may consider the problem of their CFM by focusing not only a single main category (the production one) of community forest ecosystem functions, but all the five main categories. The future availability of a fully autonomous computer ABM would be a useful simulation tool to represent such diverse SES components covering all five main categories of community forest ecosystem functions and to simulate how they interact under various possible scenarios.

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APPENDICES

Appendix 1: Contents of the semi-structured guideline used for individual interviews of local people regarding the information functions.

1. **Basic information of the informant** (name, surname, sex, age, occupation, income, the number of member(s) in a family)

2. **History and evolution of the community forestry**
   2.1 Did you know/Did your parents or grandparents tell you about stories of foundation of the community forests and why were the forests founded?
   2.2 What is the evolution of the forestry management (any significant changes, such as turning over the leader(s) or CFM committee members reaching to better or worse management practices)?

3. **CFM rules and regulations, and current CFM problems**
   3.1 Are there any written rules/regulations for CFM? If yes, where is it?
   3.2 What did you (best) remember in details of these rules/regulations?
   3.3 Who created these rules/regulations (leaders only, local villagers only, or both leaders and local villagers)?
   3.4 How long ago were these rules/regulations used in the CFM?
   3.5 During the past 10 (or 5) years, were there any cases of breaking the rules/regulations? If yes, did the punishment(s) taken follow these rules/regulations?
   3.6 Currently, are there any problems in CFM? If yes, can you clarify?

4. **NTFPs found in the community forests, and their occurrence period and farm gate price**
   4.1 How frequently do you collect NTFPs in the community forests?
   4.2 What are the NTFPs that can be found in the community forests and which part(s) of these NTFPs is(are) collected?
   4.3 In harvesting these NTFPs, do you (need to) use any special equipment?
   4.4 What is(are) the occurrence period(s) of these NTFPs? How do these NTFPs change in their productivity during the occurrence period(s)?

4.5 Which NTFPs can be sold and what is(are) the farm gate price(s) of these NTFPs?

5. Typology of NTFP harvesters and their practices and related decision-making processes

5.1 What is your main purpose of harvesting the main kinds of NTFPs in the community forests (for sale or for self-consumption in your family)?

5.2 When and how frequent (how many harvesting days a week, how many weeks a month) do you come to harvest? How long do you take for your harvesting a trip?

5.3 How much the daily amounts of harvested products? How much the daily amounts used for self-consumption?

5.4 What are your decision-making rules regarding harvesting (when and where to visit, use of seasonal harvesting patterns, etc.)?

5.5 What is(are) the practical harvesting technique(s) used for the main kinds of NTFPs recorded at the site?

Appendix 2: Criteria used for interpreting the levels of soil chemical properties and soil chemical fertility (adapted from Kheoruenromne, 1999).

Level and its score	Soil chemical property*: Organic matter (%)	Available P (ppm)	Available K (ppm)	pH condition** and its score	Soil chemical fertility*** and summation of soil chemical property scores
Very high (5)	> 4.5	> 45	> 120	Good (5)	**High (17–20)**
High (4)	> 3.5–4.5	> 25–45	> 90–120		
Moderate (3)	1.5–3.5	10–25	60–90	Moderate (3)	**Moderate (10–16)**
Low (2)	0.5–< 1.5	3–< 10	30–< 60	Poor (1)	**Low (4–9)**
Very low (1)	< 0.5	< 3	< 30		

*N is rarely included in soil chemical analysis as its quantity is fluctuated due to soil microbe activities. Therefore, the total N was not included in this criteria.

**Condition 1: Most forest plants growing best between pH values of 5.5 and 8.5, and there are enough amounts of Ca, Mg and K for plant growth in this pH range (Trisuwan, 2001; Thomas and Packham, 2007).

Condition 2: Optimum pH range for N being utilized for plant growth is 6.0–7.0 (Trisuwan, 2001).

These two conditions were used to classify the pH conditions as follows:

- Good: the pH range followed both two conditions mentioned above,
- Moderate: the pH range followed only the first condition, and
- Poor: the pH range did not follow any conditions.

***Interpreted based on the summation of scores from each soil chemical property.

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Appendix 3: Scoring criteria of each selected ecosystem function for participatory assessment of community forest ecosystem functions.

The data used for creating the criteria were mainly based on the results of the conventional assessment of community forest ecosystem functions presented in elsewhere or the data from literature conducted at natural forest ecosystems in northern Thailand. In case the data from the conventional assessment were not reasonable enough, the author used either the data from the participatory assessment of community forest ecosystem functions presented in this study, or the combined data from both the conventional and participatory assessments.

During the field investigations, it would be possible to find/record nothing in some community forest ecosystem functions. For example, there was probably no research project conducted at the site during the last five years. However, this does not mean that the community forest ecosystem function of 'research and education' is completely disappeared. Therefore, the score of 'zero' would never be given to any community forest ecosystem functions by these scoring criteria.

1. Regulation functions

1.1 Gas regulation: aboveground carbon storage (ACS)* (adapted from Pibumrung, 2007)

Score	ACS (MgC/ha)	Score	ACS (MgC/ha)
10	≥ 73	5	33–40
9	65–72	4	25–32
8	57–64	3	17–24
7	49–56	2	9–16
6	41–48	1	≤ 8

*ACS can be estimated by 50% of tree aboveground biomass (AGB) (Brown and Lugo, 1982).
And the AGB can be calculated from the Ogawa *et al.* (1965)'s allometric equations as follows:

Stem biomass (Ws) = $0.0396\,(D^2H)^{0.9326}$ kg

Branch biomass (Wb) = $0.003487\,(D^2H)^{1.027}$ kg

Leaf biomass (Wl) = $\dfrac{1}{\frac{28}{Ws+Wb} + 0.025}$ kg

AGB = Ws + Wb + Wl kg;

D is tree stem diameter at breast height (cm) and H is tree height (m).

1.2 Water supply

Score	Occurrence of water resource(s) in the forest	Ability of catchment throughout a year
10 (high)	Yes	Yes
5 (moderate)	Yes	No
1 (low)	No	n/a

1.3 Soil formation and nutrient regulation

The results from the conventional assessment of community forest ecosystem functions (presented in elsewhere) showed that the soil chemical fertility of the Lainan's community forests was low, so the average results among the seven villages of (i) the amount of litter, and (ii) the frequency to find cross wood debris (CWD) and fallen branches in the participatory assessment of community forest ecosystem functions were classified as 'low' in this scoring criteria.

1.3.1 Amount of litter

Score	Amount of litter (g)
5 (high)	≥ 621
3 (moderate)	311–620
1 (low)	≤ 310

1.3.2 Frequency to find cross wood debris (CWD) and fallen branches

Score	Frequency
5 (high)	≥ 243
3 (moderate)	122–242
1 (low)	≤ 121

2. Habitat functions

2.1 Refugee and nursery

2.1.1 Species richness of wildlife

Score	Number of wildlife species	Score	Number of wildlife species
10	≥ 55	5	25–30
9	49–54	4	19–24
8	43–48	3	13–18
7	37–42	2	7–12
6	31–36	1	≤ 6

2.1.2 Forest patch shape

Score	Forest patch shape
10 (high)	Circular
5 (moderate)	Elongated
1 (low)	Peninsular (extremely elongated)

2.1.3 Forest structure (adapted from Dumrongrojwatthana, 2004)

2.1.3.1 Diameter at breast height (DBH) class 4.5–15 cm

Score	Percentage of trees with 4.5–15 cm of DBH
5 (high)	≤ 65%
3 (moderate)	66–84%
1 (low)	≥ 85%

2.1.3.2 DBH class > 15 cm

Score	Percentage of trees	
	DBH class > 15–25 cm	DBH class > 25 cm
5 (high)	n/a	Follow at least 2 conditions*
3 (moderate)	n/a	Follow only 1 condition*
1 (low)	≤ 15%	n/a

*Condition 1: percentage of trees with DBH class > 25–35 cm ≥ 5%
Condition 2: percentage of trees with DBH class > 35–45 cm ≥ 3%
Condition 3: percentage of trees with DBH class > 45 cm ≥ 1%

3. Production functions

3.1 Food (edible NTFPs)

Score	Number of edible NTFP species	Score	Number of edible NTFP species
10	≥ 136	5	61–75
9	121–135	4	46–60
8	106–120	3	31–45
7	91–105	2	16–30
6	76– 90	1	≤ 15

3.2 Raw materials

Score	Number of tree species	Score	Number of tree species
10	≥ 73	5	33–40
9	65–72	4	25–32
8	57–64	3	17–24
7	49–56	2	9–16
6	41–48	1	≤ 8

3.3 Medicinal resources

The local evaluators in the participatory assessment of community forest ecosystem functions had limited knowledge on medicinal plants. Therefore, the author finally decided creating the scoring criteria based on the actual number of medicinal plants found in the line transects.

Score	Number of medicinal plant species	Score	Number of medicinal plant species
10	≥ 10	5	5
9	9	4	4
8	8	3	3
7	7	2	2
6	6	1	≤ 1

4. Information functions

4.1 Aesthetic information

Score	Number of location(s) in the forest with attractive landscape scenery(ies)
10 (high)	≥ 2
5 (moderate)	1
1 (low)	0

4.2 Research and education

4.2.1 Occurrence of (unofficial) nature trail(s)

Score	Occurrence of (unofficial) nature trail(s)
5 (high)	Yes
3 (moderate)	No, but be possible to have in the future
1 (low)	No, and not be possible to have in the future

4.2.2 Research (excluded this study)

Score	Number of research project(s) conducted in the forest during 2013–2017
5 (high)	≥ 2
3 (moderate)	1
1 (low)	0

4.3 Cultural creation

4.3.1 CFM rules and regulations

Score	CFM rules and regulations	Announcement to the public
5 (high)	Yes, there are.	Yes
3 (moderate)	Yes, there are.	No
1 (low)	No, there are not.	n/a

4.3.2 Enforcement of CFM rules and regulations

Score	Enforcement
5 (high)	Very strict
3 (moderate)	Moderately strict*
1 (low)	Not strict

*The village leaders could not sometimes enforce the CFM rules and regulations to punish lawbreakers.

5. Carrier functions

5.1 Habitation

Score	Occurrence of a dhamma retreat in/nearby the forest
10 (high)	Yes
5 (low)	No*

*Nonoccurrence of a dhamma retreat still had a bit high score (5) as this could make low disturbance to the forest from human activities.

5.2 Transportation

Score	Occurrence of small pathway(s) across the forest to agricultural areas
10 (high)	Yes
5 (low)	No*

*Nonoccurrence of small pathway(s) still had a bit high score (5) as this could make low disturbance to the forest from human activities.

5.3 Tourism-facilities (ecotourism)

Score	Ecotourism
10 (high)	Yes, there is.
5 (moderate)	No, there is not; but be possible to have in the future
1 (low)	No, there is not; and not be possible to have in the future

5.4 Reforestation

Score	Possible changes of the forest area in the next 5–10 years
10 (high)	Increase
5 (moderate)	Stable
1 (low)	Decrease

Literature cited

Brown, S. and Lugo, A. E. 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. Biotropica 14: 161–187.

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Pibumrung, P. 2007. Effects of Land-use Changes on Carbon Stocks: a case study in Nam Yao Sub-watershed, Nan Province, Thailand. Doctoral dissertation. Biological Sciences, Chulalongkorn University, Bangkok, Thailand.

Appendix 4: Contents of the semi-structured guideline used for individual interviews of participants after the first participatory gaming field workshop (the first model use as an initial RPG).

1. The most striking souvenir from the workshop

1.1 What do you (best) remember from the workshop?

1.2 What did you get/find interesting/learn?

The author started the interview with a couple of broad questions to break the ice and to assess if the interviewee remembers the activities occurred during the workshop or not. The author also showed the poster of photos taken during the workshop to the interviewee to refresh his/her mind before looking for further details.

2. Learning about the issues

2.1 What did you learn about:

(i) The resource dynamics influenced by the amount of annual rainfall, are there any others factors influencing the resource dynamics?; and

(ii) The decision-making where to harvest the resources and how much the amount of resources do you want to harvest?

3. Learning about situation and opinions from other participants

3.1 Do you now better understand the situation and opinions, concerns and priorities of other players, specifically their NTFP harvesting practices and related decision-making processes?

4. Collective engagement

4.1 During the second participatory gaming session, what do you think about a new harvesting rule of “equity on resource sharing” (specifically for the participants of the first day), or a new proposed scenario of “firebreak establishment” (specifically for the participants of the second day)?

4.2 Do you think that those proposed scenarios from the question 4.1 can be applied in reality both individually and collectively? If no, what are the difficulties?

5. Specific effects from the model used as an initial RPG

5.1 Do you think that the RPG can help you to better grasp the CFM issues (as mentioned in the second topic)? If yes, can you specify?

6. Anchoring of the local decision-making process in the context of networking to get the recognition and resources for implementation

6.1 Did you tell what you had done in the workshop to your family member(s), your neighbour(s), or others? If yes, what issues did you discuss? What were their reactions/responses?

7. Perspectives

7.1 Do you have any suggestions to improve the RPG model or/and the workshop proceedings to be used/organized in the future?

7.2 Do you have any suggestions about the suitable content(s) of future sessions and about who should participate in?

Appendix 5: Contents of the semi-structured guideline used for individual interviews of the participants after the second participatory gaming and simulation field workshop (the CoComForest model use as a cRPG).

1. The most striking souvenir from the workshop

1.1 What do you (best) remember from the workshop?

1.2 What did you get/find interesting/learn?

The author started the interview with a couple of broad questions to break the ice and to assess if the interviewee remembers the activities that occurred during the workshop or not. The author also showed the poster of photos taken during the workshop to the interviewee to refresh his/her mind before looking for further details.

2. Learning about the issues

2.1 What did you learn about (i) the resource dynamics influenced by the number of harvesters, (ii) the benefits from the establishment of firebreaks and declaration of protected areas, and (iii) the roles of outsiders to harvest NTFPs in the community forests?

2.2 Did you learn new things regarding the issue of the current CFM problem(s) examined?

2.3 Did you feel that it is urgent to take the actions upon this(these) CFM problem(s)?

2.4 Did you get better insight in the consequence(s) of the CFM problem(s)?

2.5 Did you learn new kinds of possible ways to improve the current situation?

3. Learning about situation and opinions from other participants

3.1 Did the workshop process encourage you to exchange your viewpoints with others?

3.2 Do you now better understand situation and opinions, concerns and priorities of other players, specifically their NTFP harvesting practices and related decision-making processes?

3.3 What were the critical topics you need to discuss together?

3.4 What was the result(s) of the discussion(s): what things did you agree on, and on what were the points of disagreement?

4. Collective engagement

4.1 During the second participatory gaming and simulation session, what do you think about the collective engagement to establish firebreaks leading to the improvement of resource availability in the community forests? How far they can be done in reality?

4.2 Did the workshop process raise your engagement to solve the CFM problem(s)?

4.3 Did the workshop process mobilize the community (the representatives from all seven villages and the SAO) as a whole? Does everyone feel engaged to solve the CFM problem issue(s) together? Are there any fractions/disagreements?

4.4 Did the community come to a joint agreement?

4.5 Did you observe any changes in some participants' relationships during the workshop process? If yes, how did they change?

5. Specific effects of the model used as a cRPG

5.1 Do you think that the cRPG can help you to better grasp the CFM issues (as mentioned in the second topic) and understand their effects/impact? If yes, can you specify?

5.2 Do you think that the model can help you to identify the possible ways to improve the current unsatisfactory CFM situation?

6. Capacity building

6.1 Did you (or your leaders) organize additional meetings on the CFM issues examined (as mentioned in the second topic) without anyone from the research team?

6.2 Are you interested and capable to lead the workshop process in the future to tackle similar problems?

7. Anchoring of the local decision-making process in the context of networking to get the recognition and resources for implementation

7.1 Did you tell what you had done in the workshop to your family member(s), your neighbour(s), or others? If yes, what issues did you discuss? What were their reactions/responses?

8. Actions and new practices

8.1 Are there any new actions or/and practices in CFM coming out of the workshop, which have never been proposed before?

9. Perspectives

9.1 Do you have any suggestions to improve the cRPG simulation tool or/and the workshop proceedings to be used/organized in the future?

9.2 Do you have any suggestions about the suitable content(s) of future sessions and about who should participate in?

Appendix 6: List of NTFPs found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand and their farm gate price in THB/unit; based on focus group discussion and individual in-depth interviews.

NO	Type of NTFPs	Vernacular name(s)	Farm gate price		Remark
1	Plant/Algae	กระชายป่า	15	THB/ kg	
2	Plant/Algae	กล้วยแค้		n/a	
3	Plant/Algae	กล้วย spp.		n/a	
4	Plant/Algae	กลอย	20	THB/ small dish	Dish diameter ≈ 15 cm
5	Plant/Algae	กุ๊ก	5	THB/ handful bundle	
6	Plant/Algae	ขนุนหำเหล้า		n/a	
7	Plant/Algae	ข่า	20	THB/ kg	
8	Plant/Algae	แคบ/ตำลึง		n/a	
9	Plant/Algae	แคป่า		n/a	
10	Plant/Algae	ดอกก้าน	20	THB/ handful bundle	
11	Plant/Algae	ดอกกระเจียว/ดาหลา/อากึบ/อาว	20	THB/ handful bundle	
12	Plant/Algae	บุก	10–20	THB/ handful bundle	
13	Plant/Algae	ใบบัวบก/ผักหนอก		n/a	
14	Plant/Algae	เปลือกขำเกาะ	5	THB/ handful bundle	
15	Plant/Algae	ผักกูด	10	THB/ handful bundle	
16	Plant/Algae	ผักโขม		n/a	
17	Plant/Algae	ผักบอน	5–10	THB/ handful bundle	
18	Plant/Algae	ผักสะลิด	5	THB/ handful bundle	
19	Plant/Algae	ผักสะแล	5	THB/ handful bundle	
20	Plant/Algae	ผักสาบ	10	THB/ small dish	Dish diameter ≈ 15 cm
		ผักสาบ (ผล)	10	THB/ 6 fruits	
21	Plant/Algae	ผักไส้ตัน	5	THB/ handful bundle	
22	Plant/Algae	ผักหนาม	10–20	THB/ handful bundle	
23	Plant/Algae	ผักหวานป่า	200	THB/ kg	
24	Plant/Algae	มะกอกป่า	20	THB/ kg	Also 5 THB/3 fruits
25	Plant/Algae	มะเกว๋น		n/a	
26	Plant/Algae	มะขามป้อม	10–15	THB/ kg	
27	Plant/Algae	มะแขว้ง/มะเขือพวง		n/a	
28	Plant/Algae	มะค่าป่า	5	THB/ kg	
		มะค่าป่า (ผล)	20	THB/ kg	
29	Plant/Algae	มะเคาะป่า/หมากเคาะ	20	THB/ liter	
30	Plant/Algae	มะจิ้ม		n/a	
31	Plant/Algae	มะตึ่ง/หมากตึ่ง		n/a	
32	Plant/Algae	มะตูม	10	THB/ small dish	Dish diameter ≈ 15 cm
33	Plant/Algae	มะนอด		n/a	
34	Plant/Algae	มะนะ/หมากนะ		n/a	
35	Plant/Algae	มะปีน/หมากปีน		n/a	
36	Plant/Algae	มะไฟป่า		n/a	
37	Plant/Algae	มะม่วงไข่		n/a	
38	Plant/Algae	มะมื่น/หมากมื่น		n/a	

NO	Type of NTFPs		Vernacular name(s)	Farm gate price		Remark
39	Plant/Algae		มะเม่า/หมากเม่า	5	THB/ handful bundle	
40	Plant/Algae		มะระขี้นก		n/a	
41	Plant/Algae		มะลิดไม้	10	THB/ pod	
42	Plant/Algae		มะหวดเหล้า/หมากขวดเหล้า		n/a	
43	Plant/Algae		มะฮ่อย	20	THB/ small dish	Dish diameter ≈ 15 cm
44	Plant/Algae		มันป่า	20	THB/ kg	
45	Plant/Algae		ลำไยป่า		n/a	
46	Plant/Algae		ส้มจั๊วะ		n/a	
47	Plant/Algae		ส้มป่อย	5	THB/ small dish	Dish diameter ≈ 15 cm
48	Plant/Algae		สะกึยไม้ตาเสือ		n/a	
49	Plant/Algae		สาหร่ายเตา/เทา	10–20	THB/ handful bundle	
50	Plant/Algae		หญ้านาง		n/a	
51	Plant/Algae		หน่อไม้ซาง	50	THB/ kg	Sell in mixtures of other kinds of bamboo shoots.
52	Plant/Algae		หน่อไม้บง	50	THB/ kg	
53	Plant/Algae		หน่อไม้ไร่	50	THB/ kg	
54	Plant/Algae		หน่อไม้หวาย	50	THB/ kg	
55	Plant/Algae		หนามปู่ย่า	5	THB/ handful bundle	
56	Plant/Algae		หมากก้าย	10	THB/ kg	
57	Plant/Algae		หมากกิ้ม		n/a	
58	Plant/Algae		หมากตัน		n/a	
59	Plant/Algae		หมากปุ่มเป้ง/หัวปุ่มเป้ง		n/a	
60	Plant/Algae		หมากเม่าส้ม		n/a	
61	Plant/Algae		หมากลิ่นแจ้		n/a	
62	Plant/Algae		หมากส้มจิ้น		n/a	
63	Plant/Algae		หมากสุ้มเสี้ยน		n/a	
64	Plant/Algae		หมากหวด		n/a	
65	Plant/Algae		หวาย		n/a	
66	Animal	Earthworm	ไส้เดือนดิน		n/a	
67	Animal	Mollusk	หอยขม		n/a	
68	Animal	Mollusk	หอยโข่ง		n/a	
69	Animal	Mollusk	หอยจูบ		n/a	
70	Animal	Mollusk	หอยป้อม		n/a	
71	Animal	Mollusk	หอยเล็กจาง		n/a	
72	Animal	Mollusk	หอย spp.	20	THB/ small dish	Dish diameter ≈ 15 cm
73	Animal	Crustacean	กุ้งฝอย	200	THB/ kg	
74	Animal	Crustacean	ปูนา	100	THB/ kg	Also 20 THB/small dish
75	Animal	Crustacean	ปูแป้ง	20	THB/ 3 animals	
76	Animal	Crustacean	ปูผา	30	THB/ kg	
77	Animal	Insect/Arachnid	ไข่มดแดง	250	THB/ kg	
78	Animal	Insect/Arachnid	ไข่มดฮี่	300	THB/ kg	
79	Animal	Insect/Arachnid	จั๊กจั่น		n/a	
80	Animal	Insect/Arachnid	จิ้งหรีด/จี้กุ่ง	2	THB/ animal	
81	Animal	Insect/Arachnid	ด้วงกว่าง/แมลงกว่าง	50	THB/ animal	
82	Animal	Insect/Arachnid	น้ำผึ้ง	200	THB/ 700 ml	

NO	Type of NTFPs		Vernacular name(s)	Farm gate price		Remark
83	Animal	Insect/Arachnid	บึ้ง	20	THB/ animal	
84	Animal	Insect/Arachnid	แมลงมัน	400	THB/ kg	
85	Animal	Insect/Arachnid	แมลงเม่า		n/a	
86	Animal	Insect/Arachnid	รังต่อ	400	THB/ kg	
87	Animal	Insect/Arachnid	รังแตน		n/a	
88	Animal	Insect/Arachnid	รังผึ้งมิ้ม	20	THB/ comb	
89	Animal	Insect/Arachnid	หนอนไม้ไผ่/หนอนรถด่วน	200	THB/ kg	
90	Animal	Fish	ปลากั้ง	150	THB/ kg	
91	Animal	Fish	ปลาช่อน	100	THB/ kg	
92	Animal	Fish	ปลาซาบู่		n/a	
93	Animal	Fish	ปลาซิว	20	THB/ cup of tea	
94	Animal	Fish	ปลาดุก	80	THB/ kg	
95	Animal	Fish	ปลาบู่	20	THB/ cup of tea	
96	Animal	Fish	ปลาปก		n/a	
97	Animal	Fish	ปลาหางกล้วย		n/a	
98	Animal	Amphibian	กบจุก		n/a	
99	Animal	Amphibian	กบนา		n/a	
100	Animal	Amphibian	กบ spp.	150	THB/ kg	
101	Animal	Amphibian	เขียดตาแดง		n/a	
102	Animal	Amphibian	เขียด spp.	100	THB/ kg	
103	Animal	Amphibian	อึ่งอ่างไฟ	50	THB/ kg	
104	Animal	Amphibian	อึ่งอ่าง spp.	200	THB/ kg	
105	Animal	Reptile	งูเหลือม	80	THB/ m	
106	Animal	Reptile	งูสิงคาน		n/a	
107	Animal	Reptile	งูสิงสา		n/a	
108	Animal	Reptile	งูสิง spp.	100–150	THB/ animal	
109	Animal	Reptile	งูเห่า		n/a	
110	Animal	Reptile	เต่า		n/a	
111	Animal	Reptile	แย้	20	THB/ animal	
112	Animal	Reptile	แลน	200–450	THB/ kg	
113	Animal	Reptile	เหี้ย		n/a	
114	Animal	Avian	ไก่ป่า	150–250	THB/ animal	
115	Animal	Avian	ไข่ไก่/ไข่นก	5	THB/ egg	
116	Animal	Avian	แจ้		n/a	
117	Animal	Avian	นกก้นปู้ด/นกกระปูด	80	THB/ animal	
118	Animal	Avian	นกกระจอก	30	THB/ animal	
119	Animal	Avian	นกกระจิบ	30	THB/ animal	
120	Animal	Avian	นกกวิ๊ด	300	THB/ animal	
121	Animal	Avian	นกกางเขน/เจี๊ยบโก้ง		n/a	
122	Animal	Avian	นกเขาเขียว		n/a	
123	Animal	Avian	นกเขาคัน		n/a	
124	Animal	Avian	นกเขาซอย		n/a	
125	Animal	Avian	นกเขา spp.	30	THB/ animal	
126	Animal	Avian	นกคั้วะ	20	THB/ animal	

NO	Type of NTFPs		Vernacular name(s)	Farm gate price		Remark
127	Animal	Avian	นกเค้า		n/a	
128	Animal	Avian	นกแซว		n/a	
129	Animal	Avian	นกถัวเมาะ		n/a	
130	Animal	Avian	นกถัว spp.		n/a	
131	Animal	Avian	นกยูง		n/a	
132	Animal	Avian	นกหงอน		n/a	
133	Animal	Avian	นกอีปู่		n/a	
134	Animal	Avian	นกเอี้ยง		n/a	
135	Animal	Mammal	กระต่ายป่า		n/a	
136	Animal	Mammal	กระแต/ไน	50–80	THB/ animal	
137	Animal	Mammal	กระรอก/ฮอก	120	THB/ animal	
138	Animal	Mammal	เก้ง/พาน	300	THB/ kg	
139	Animal	Mammal	จ้อน/บ่าง	50	THB/ animal	
140	Animal	Mammal	ตุ่น	300–400	THB/ kg	Also 100 THB/animal
141	Animal	Mammal	นิ่ม/ลิ่น		n/a	
142	Animal	Mammal	พังพอน	100	THB/ animal	
143	Animal	Mammal	เม่น		n/a	
144	Animal	Mammal	ลิงลม		n/a	
145	Animal	Mammal	หนูป่า	30–50	THB/ animal	
146	Animal	Mammal	หมาไน		n/a	
147	Animal	Mammal	หมีควาย		n/a	
148	Animal	Mammal	หมูป่า	200	THB/ kg	
149	Animal	Mammal	อ้น		n/a	
150	Animal	Mammal	อีเห็น		n/a	
151	Edible mushroom		เห็ดกันจ้อง	*100	THB/ kg	
152	Edible mushroom		เห็ดแก้น	*100	THB/ kg	
153	Edible mushroom		เห็ดขมิ้น	*100	THB/ kg	
154	Edible mushroom		เห็ดขอนขาว	*100	THB/ kg	
155	Edible mushroom		เห็ดข่า	*100	THB/ kg	
156	Edible mushroom		เห็ดข้าวเหนียว	*100	THB/ kg	
157	Edible mushroom		เห็ดข้าวตอก	*100	THB/ kg	
158	Edible mushroom		เห็ดโคน	150	THB/ kg	Also *100 THB/kg
159	Edible mushroom		เห็ดไคร้น้ำ	*100	THB/ kg	Also 20 THB/4 units
160	Edible mushroom		เห็ดไคร้บก	*100	THB/ kg	
161	Edible mushroom		เห็ดจั่น	*100	THB/ kg	
162	Edible mushroom		เห็ดซ่าห่าง	*100	THB/ kg	
163	Edible mushroom		เห็ดด่าน/เปา	300	THB/ kg	Also *100 THB/kg
164	Edible mushroom		เห็ดแดงดง	*100	THB/ kg	
165	Edible mushroom		เห็ดถอบ	200	THB/ liter	
166	Edible mushroom		เห็ดถ่านไฟ	*100	THB/ kg	
167	Edible mushroom		เห็ดน้ำผึ้ง/น้ำมิ้ม	*100	THB/ kg	
168	Edible mushroom		เห็ดน้ำหมาก	*100	THB/ kg	
169	Edible mushroom		เห็ดไผ่ซาง	*100	THB/ kg	
170	Edible mushroom		เห็ดไผ่ไร่	*100	THB/ kg	

NO	Type of NTFPs	Vernacular name(s)	Farm gate price	Remark
171	Edible mushroom	เห็ดฝอย	*100 THB/ kg	
172	Edible mushroom	เห็ดพุงหมู	*100 THB/ kg	
173	Edible mushroom	เห็ดมะเขือ	*100 THB/ kg	
174	Edible mushroom	เห็ดมันอึ่ง	*100 THB/ kg	
175	Edible mushroom	เห็ดระโงกขาว	150 THB/ kg	Also *100 THB/kg
176	Edible mushroom	เห็ดระโงกเหลือง	150 THB/ kg	Also *100 THB/kg
177	Edible mushroom	เห็ดลม	250 THB/ kg	
178	Edible mushroom	เห็ดสะโละ/หูหนู	*100 THB/ kg	
179	Edible mushroom	เห็ดหน้าแป้ง	*100 THB/ kg	
180	Edible mushroom	เห็ดหน้าม่อย	*100 THB/ kg	
181	Edible mushroom	เห็ดหัวเข่า	*100 THB/ kg	
182	Edible mushroom	เห็ดหาดแดง	*100 THB/ kg	
183	Edible mushroom	เห็ดหาดเหลือง	*100 THB/ kg	

‘n/a’ for the farm gate price refers to “no trading report”.
*Edible mushrooms with low farm gate price (< 150 THB/unit) were sold in mixtures by approximately 100 THB/kg.

Appendix 7: List of trees found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand; based on ecological field investigations.

NO	Family	Scientific name	Vernacular name(s)
1	Anacardiaceae	*Gluta* sp.	รัก/ฮัก
2	Anacardiaceae	*Lannea coromandelica*	กุ๊ก/อ้อยช้าง
3	Anacardiaceae	*Spondias pinnata*	กูก/มะกอก
4	Annonaceae	*Miliusa velutina*	ขางหัวหมู/หางรอก
5	Annonaceae	*Mitrephora vandaeflora*	ปอแฮด/แฮด
6	Bignoniaceae	*Dolichandrone serrulata*	แคขาว/แคป่า
7	Bombacaceae	*Bombax ceiba*	งิ้ว/งิ้วแดง
8	Burseraceae	*Canarium subulatum*	มะกอกเกลื้อน/มะเกิ้ม
9	Burseraceae	*Garuga pinnata*	แขกเต้า/คร้ำ/ตะคร้ำ
10	Combretaceae	*Terminalia chebula* var. *chebula*	มะนะ/สมอไทย
11	Combretaceae	*Terminalia mucronata*	ตะแบกเลือด/เป๋ย/เปื๋อย
12	Dilleniaceae	*Dillenia aurea* var. *aurea*	ส้าน/ส้านหิ่ง
13	Dipterocarpaceae	*Dipterocarpus obtusifolius*	ยางเหียง/เหียง
14	Dipterocarpaceae	*Dipterocarpus tuberculatus*	ตึง/พลวง
15	Dipterocarpaceae	*Dipterocarpus* sp.	ยางดง
16	Dipterocarpaceae	*Hopea odorata* var. *odorata*	ตะเคียนทอง
17	Dipterocarpaceae	*Shorea obtusa*	แงะ/เต็ง
18	Dipterocarpaceae	*Shorea roxburghii*	พะยอม
19	Dipterocarpaceae	*Shorea siamensis*	เปา/รัง
20	Dipterocarpaceae	*Shorea* sp.	เปาเดือย/รังเดือย
21	Ebenaceae	*Diospyros ehretioides*	ตับเต่าต้น/มะพลับดง
22	Ebenaceae	*Diospyros mollis*	มะเกลือ
23	Ebenaceae	*Diospyros rhodocalyx*	ถ่านไฟผี
24	Euphorbiaceae	*Antidesma* sp.	เม่า
25	Euphorbiaceae	*Aporosa* sp.	เหมียด/เหมือด
26	Euphorbiaceae	*Cleidion spiciflorum*	ดีหมี
27	Euphorbiaceae	*Phyllanthus emblica*	มะขามป้อม
28	Fagaceae	*Quercus* sp.	ก่อ
29	Hypericaceae	*Cratoxylum* sp.	ติ้ว
30	Irvingiaceae	*Irvingia malayana*	กระบก/มะมื่น
31	Labiatae	*Gmelina arborea*	ซ้อ/แต้งขาว
32	Labiatae	*Tectona grandis*	สัก
33	Labiatae	*Vitex canescens*	ผ่าเสี้ยน/เสี้ยน
34	Labiatae	*Vitex limoniifolia*	ตีนนก
35	Lecythidaceae	*Careya sphaerica*	กระโดน/กระปุย/ปุย/หูกวาง
36	Leguminosae-Caesalpinioideae	*Bauhinia* sp.	เสี้ยว/เสี้ยวป่า
37	Leguminosae-Caesalpinioideae	*Cassia garrettiana*	ขี้เหล็กป่า/แสมสาร
38	Leguminosae-Mimosoideae	*Parkia sumatrana*	มะขามเฒ่า/เอกราช
39	Leguminosae-Mimosoideae	*Xylia xylocarpa* var. *kerrii*	แดง
40	Leguminosae-Papilionoideae	*Dalbergia cultrata*	กระพี้เขาควาย/เก็ดดำ

NO	Family	Scientific name	Vernacular name(s)
41	Leguminosae-Papilionoideae	*Dalbergia oliveri*	เก็ดแดง/เค็ดแดง/ชิงชัน
42	Leguminosae-Papilionoideae	*Millettia* sp.	กระพี้
43	Leguminosae-Papilionoideae	*Pterocarpus macrocarpus*	ประดู่ป่า
44	Loganiaceae	*Strychnos nux-blanda*	มะติ่ง/มะตึ่ง
45	Lythraceae	*Lagerstroemia cochinchinensis* var. *ovalifolia*	ตะแบก/ตะแบกเกรียบ
46	Lythraceae	*Lagerstroemia tomentosa*	เสลา/เส้า/เส้าขาว
47	Meliaceae	*Chukrasia velutina*	ยมหิน/โยมหิน
48	Opiliaceae	*Melientha suavis*	ผักหวานป่า
49	Primulaceae	*Embelia subcoriacea*	นมนาง
50	Rubiaceae	*Catunaregam spathulifolia*	หนามแท่ง
51	Rubiaceae	*Dioecrescis erythroclada*	มะกัง/มะคัง/มะคังแดง
52	Rubiaceae	*Haldina cordifolia*	กว้าว/ขว้าว/ตุ้มควาย
53	Rubiaceae	*Hymenodictyon orixense*	ส้มกบ
54	Rubiaceae	*Metadina trichotoma*	ขมิ้น/ขมิ้นต้น
55	Rubiaceae	*Mitragyna speciosa*	กระท่อม/ลองเลาะ
56	Rubiaceae	*Morinda tomentosa*	ยอป่า/สะกึย
57	Sapindaceae	*Litchi chinensis*	ลิ้นจี่ป่า
58	Sapindaceae	*Schleichera oleosa*	เคาะ/ตะคร้อ/มะเคาะ/มะโจ้ก
59	Theaceae	*Eurya acuminata* var. *wallichiana*	ปลายสาน/แฮพันชั้น/ไฮพันชั้น
60	Tiliaceae	*Berrya mollis*	เลียง
61	Tiliaceae	*Colona flagrocarpa*	ยาบ/ยาบใบยาว
62	n/a	Unknown 1	ก้าย
63	n/a	Unknown 2	เขียน
64	n/a	Unknown 3	จิ้ม
65	n/a	Unknown 4	ตอมต๊อก
66	n/a	Unknown 5	ผักพ้า
67	n/a	Unknown 6	ลืมจู้/ลืมชู้

Appendix 8: List of soil fauna orders found in each community forest at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

NO	Order	Number of individuals							
		Village 1	Village 2	Village 3	Village 4	Village 5	Village 6	Village 7	All the seven villages
1	Acari	1	2	0	2	1	0	0	**6**
2	Araneae	0	2	1	3	1	2	1	**10**
3	Blattodea	0	2	0	0	0	0	0	**2**
4	Coleoptera	0	7	2	0	1	0	4	**14**
5	Collembola	0	1	0	1	0	0	0	**2**
6	Diplura	0	0	1	0	1	7	2	**11**
7	Diptera	0	0	1	5	0	0	0	**6**
8	Hymenoptera	5	14	10	11	21	16	8	**85**
9	Isopoda	0	0	0	3	0	0	0	**3**
10	Isoptera	0	0	3	3	6	6	0	**18**
11	Neuroptera	7	0	0	0	0	0	0	**7**
12	Orthoptera	1	3	0	0	0	2	2	**8**
13	Polydesmida	0	0	0	2	0	0	0	**2**
14	Pseudoscorpiones	0	0	0	2	0	0	0	**2**
15	Psocoptera	0	1	1	0	0	0	0	**2**
16	Symphyla	0	2	0	0	0	0	0	**2**
17	Unknown 1 (centipedes)	2	0	0	1	0	0	0	**3**
18	Unknown 2	0	0	0	10	0	0	0	**10**
Number of individuals		**16**	**34**	**19**	**43**	**31**	**33**	**17**	**193**
Number of orders		**5**	**9**	**7**	**11**	**6**	**5**	**5**	**18**

Appendix 9: List of wild mushrooms found in the community forests at Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand and their edible status classified into the following three groups: edible (🍽), non-edible (☠), and no edible report (?); based on ecological field investigations.

NO	Phylum/Class	Order	Family	Genus	Scientific name	Vernacular name	Edible status		
							🍽	☠	?
1	Basidiomycota/Basidiomycetes	Agaricales	Agaricaceae	*Agaricus*	*Agaricus trisulphuratus*	กะเหรี่ยงส้ม		☠	
2	Basidiomycota/Basidiomycetes	Agaricales	Agaricaceae	n/a	Agaricaceae sp.1	n/a		☠	
3	Basidiomycota/Basidiomycetes	Agaricales	Agaricaceae	n/a	Agaricaceae sp.2	n/a		☠	
4	Basidiomycota/Basidiomycetes	Agaricales	Clavariaceae	*Clavulinopsis*	*Clavulinopsis corallino-rosacea*	ฝอย	🍽		
5	Basidiomycota/Basidiomycetes	Agaricales	Clavariaceae	*Ramaria*	*Ramaria botrytis*	ปะการังยอดแดงอมชมพู	🍽		
6	Basidiomycota/Basidiomycetes	Agaricales	Coprinaceae	*Coprinus*	*Coprinus plicatilis*	มันเล็ก			?
7	Basidiomycota/Basidiomycetes	Agaricales	Lycoperdaceae	*Lycoperdon*	*Lycoperdon* sp.	ลูกฝุ่น		☠	
8	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	*Marasmius*	*Marasmius* sp.1	n/a		☠	
9	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	*Marasmius*	*Marasmius* sp.2	n/a		☠	
10	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.1	n/a		☠	
11	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.2	n/a		☠	
12	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.3	n/a		☠	
13	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.4	n/a		☠	
14	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.5	n/a	🍽		
15	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.6	n/a			?
16	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.7	n/a		☠	
17	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.8	n/a		☠	
18	Basidiomycota/Basidiomycetes	Agaricales	Marasmiaceae	n/a	Marasmiaceae sp.9	n/a		☠	
19	Basidiomycota/Basidiomycetes	Agaricales	Pleurotaceae	*Pleurotus*	*Pleurotus* sp.	n/a	🍽		
20	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita caesarea*	ระโงกแดง	🍽		

NO	Phylum/Class	Order	Family	Genus	Scientific name	Vernacular name	Edible status		
							🍽	☠	?
21	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita hemibapha jananica*	ระโงกเหลือง	🍽		
22	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita hemibapha similis*	ไข่นกเหลือง	🍽		
23	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita princeps*	ระโงกขาว	🍽		
24	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita vaginata vaginata*	ไข่นก	🍽		
25	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita virginea*	ระโงกหนาม		☠	
26	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita* sp.1	ป่าว		☠	
27	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita* sp.2	ระโงกตีนต้น		☠	
28	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita* sp.3	ระโงกยาง		☠	
29	Basidiomycota/Basidiomycetes	Agaricales	Pluteaceae	*Amanita*	*Amanita* sp.4	n/a		☠	
30	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Macrocybe*	*Macrocybe crassa*	จั่น	🍽		
31	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Termitomyces*	*Termitomyces indicus*	โคนเล็ก	🍽		
32	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Termitomyces*	*Termitomyces striatus* ssp.1	โคนดำ	🍽		
33	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Termitomyces*	*Termitomyces striatus* ssp.2	โคนแดง	🍽		
34	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Termitomyces*	*Termitomyces tyleranus*	โคนพาน	🍽		
35	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Termitomyces*	*Termitomyces* sp.1	โคนขี้ไก่	🍽		
36	Basidiomycota/Basidiomycetes	Agaricales	Tricholomataceae	*Termitomyces*	*Termitomyces* sp.2	n/a	🍽		
37	Basidiomycota/Basidiomycetes	Agaricales	n/a	n/a	Agaricales sp.1	n/a		☠	
38	Basidiomycota/Basidiomycetes	Agaricales	n/a	n/a	Agaricales sp.2	n/a		☠	
39	Basidiomycota/Basidiomycetes	Agaricales	n/a	n/a	Agaricales sp.3	n/a		☠	
40	Basidiomycota/Basidiomycetes	Agaricales	n/a	n/a	Agaricales sp.4	n/a		☠	
41	Basidiomycota/Basidiomycetes	Auriculariales	Auriculariaceae	*Auricularia*	*Auricularia tenuis*	หูหนูป่า		☠	
42	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Boletellus*	*Boletellus emodensis*	ผึ้งนกยูง	🍽		
43	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Boletus*	*Boletus obscureumbrinus*	ก่อ	🍽		
44	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Boletus*	*Boletus subtomentosus*	ผึ้งพระจันทร์เสี้ยว			?

NO	Phylum/Class	Order	Family	Genus	Scientific name	Vernacular name	Edible status		
							🍽	☠	?
45	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Boletus*	*Boletus* sp.1	n/a		☠	
46	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Boletus*	*Boletus* sp.2	n/a		☠	
47	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Heimiella*	*Heimiella retispora*	ปอดม้า	🍽		
48	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Heimioporus*	*Heimioporus japonica*	กันจ้อง	🍽		
49	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Pulveroboletus*	*Pulveroboletus ravenelii*	มันอึ่งดิน	🍽		
50	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Retiboletus*	*Retiboletus ornatipes*	มิ้ม	🍽		
51	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Tylopilus*	*Tylopilus griseocarneus*	ผึ้งเทาขาข่ายดำ			?
52	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	*Tylopilus*	*Tylopilus* sp.	n/a	🍽		
53	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	n/a	Boletaceae sp.1	n/a		☠	
54	Basidiomycota/Basidiomycetes	Boletales	Boletaceae	n/a	Boletaceae sp.2	n/a		☠	
55	Basidiomycota/Basidiomycetes	Boletales	Hymenogasteraceae	*Mycoamaranthus*	*Mycoamaranthus cambodgensis*	ข้าวเหนี่ยง	🍽		
56	Basidiomycota/Basidiomycetes	Boletales	Sclerodermataceae	*Astraeus*	*Astraeus* sp.	ถอบ	🍽		
57	Basidiomycota/Basidiomycetes	Boletales	Sclerodermataceae	*Pisolithus*	*Pisolithus* sp.	ไข่อึ่ง		☠	
58	Basidiomycota/Basidiomycetes	Boletales	Sclerodermataceae	*Scleroderma*	*Scleroderma sinnamariense*	ก้อนฝุ่นเหลืองทอง			?
59	Basidiomycota/Basidiomycetes	Boletales	Sclerodermataceae	*Scleroderma*	*Scleroderma* sp.	n/a	🍽		
60	Basidiomycota/Basidiomycetes	Cantharellales	Cantharellaceae	*Cantharellus*	*Cantharellus cibrius*	มันปูใหญ่	🍽		
61	Basidiomycota/Basidiomycetes	Cantharellales	Cantharellaceae	*Craterellus*	*Craterellus aureus*	ขมิ้นน้อย	🍽		
62	Basidiomycota/Basidiomycetes	Cantharellales	Cantharellaceae	*Craterellus*	*Craterellus odoratus*	ขมิ้นใหญ่	🍽		
63	Basidiomycota/Basidiomycetes	Cantharellales	Clavulinaceae	*Clavulina*	*Clavulina cristata*	ปะการังหงอนไก่	🍽		
64	Basidiomycota/Basidiomycetes	Hymenochaetales	Hymenochaetaceae	*Phellinus*	*Phellinus rimosus*	ถ่านไฟผี		☠	
65	Basidiomycota/Basidiomycetes	Polyporales	Ganodermataceae	n/a	Ganodermataceae sp.1	n/a		☠	
66	Basidiomycota/Basidiomycetes	Polyporales	Ganodermataceae	n/a	Ganodermataceae sp.2	n/a		☠	
67	Basidiomycota/Basidiomycetes	Polyporales	Ganodermataceae	n/a	Ganodermataceae sp.3	n/a		☠	
68	Basidiomycota/Basidiomycetes	Polyporales	Ganodermataceae	n/a	Ganodermataceae sp.4	n/a		☠	

NO	Phylum/Class	Order	Family	Genus	Scientific name	Vernacular name	Edible status		
							🍽	☠	?
69	Basidiomycota/Basidiomycetes	Polyporales	Ganodermataceae	n/a	Ganodermataceae sp.5	n/a		☠	
70	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	*Lentinus*	*Lentinus edodes*	หอม	🍽		
71	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	*Lentinus*	*Lentinus polychrous*	ลม	🍽		
72	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	*Lentinus*	*Lentinus sajor-caju*	หูแมว	🍽		
73	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	*Lentinus*	*Lentinus squarrosulus*	ขอนขาว	🍽		
74	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	*Lentinus*	*Lentinus strigosus*	ไผ่	🍽		
75	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	*Polyporus*	*Polyporus squamosus*	มันอึ่ง	🍽		
76	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	n/a	Polyporaceae sp.1	n/a		☠	
77	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	n/a	Polyporaceae sp.2	n/a		☠	
78	Basidiomycota/Basidiomycetes	Polyporales	Polyporaceae	n/a	Polyporaceae sp.3	n/a		☠	
79	Basidiomycota/Basidiomycetes	Polyporales	n/a	n/a	Polyporales sp.	n/a		☠	
80	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Lactarius*	*Lactarius deliciosus*	ซ่าห่าง	🍽		
81	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Lactarius*	*Lactarius flavidulus*	ข่า	🍽		
82	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Lactarius*	*Lactarius hygrophoroides*	หาดส้ม	🍽		
83	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Lactarius*	*Lactarius piperatus*	ข่าเหลือง	🍽		
84	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Lactarius*	*Lactarius volemus*	หาด	🍽		
85	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula alboareolata* ssp.1	น้ำข้าว	🍽		
86	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula alboareolata* ssp.2	หน้าแป้ง	🍽		
87	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula cyanoxantha*	หน้าปั๋ง	🍽		
88	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula densifolia*	ถ่านเล็ก	🍽		
89	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula emetica*	แดง (ขาขาว)	🍽		
90	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula foetens*	พุงหมู	🍽		
91	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula nigricans*	ถ่านใหญ่	🍽		
92	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula rosacea*	แดง (ขาแดง)	🍽		

NO	Phylum/Class	Order	Family	Genus	Scientific name	Vernacular name	Edible status		
							🍽	☠	?
93	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula virescens*	ด่าน	🍽		
94	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula* sp.1	ดอกมอก	🍽		
95	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	*Russula*	*Russula* sp.2	n/a	🍽		
96	Basidiomycota/Basidiomycetes	Russulales	Russulaceae	n/a	Russulaceae sp.	n/a	🍽		
97	Basidiomycota/Basidiomycetes	Russulales	Stereaceae	*Stereum*	*Stereum complicatum*	แก้น			?
98	Basidiomycota/Basidiomycetes	Russulales	Stereaceae	*Stereum*	*Stereum ostrea*	แก้นส้ม		☠	
99	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 01	n/a			?
100	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 02	n/a			?
101	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 03	n/a		☠	
102	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 04	n/a		☠	
103	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 05	n/a			?
104	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 06	n/a		☠	
105	Basidiomycota/Basidiomycetes	n/a	n/a	n/a	Unknown 07	n/a		☠	

Appendix 10: Raw data record and raw score from the participatory assessment of community forest ecosystem functions in each village of Lainan Subdistrict, Wiang Sa District, Nan Province, northern Thailand.

DATA RECORD SHEET **VILLAGE NO 1**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	68	MgC/ha	9/10		
1.2 Water supply	Yes	No	5/10	**18**	**60**
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	246	g	1/5	**30**	**100**
1.3.2 Frequency to find CWD or fallen branches	165	(no unit)	3/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	29	species	5/10		
2.1.2 Forest patch shape	Elongated		5/10		
2.1.3 Forest structure				**18**	**60**
2.1.3.1 DBH class 4.5–15 cm	39	%	5/5		
2.1.3.2 DBH class > 15–25 cm	32	%	3/5	**30**	**100**
DBH class > 25–35 cm	27	%			
DBH class > 35–45 cm	2	%			
DBH class > 45 cm	0	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	80	species	6/10	**11**	**37**
3.2 Raw materials (number of tree species)	19	species	3/10		
3.3 Medicinal resources	2	species	2/10	**30**	**100**
4. Information functions					
4.1 Aesthetic information (number of sceneries)	0	scenery(ies)	1/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	No	Possible	3/5	**11**	**37**
4.2.1 Research (number of research projects)	0	project(s)	1/5		
4.3 Cultural creation				**30**	**100**
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Moderately strict		3/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	No		5/10	**25**	**63**
5.2 Transportation (occurrence of small pathways)	Yes		10/10		
5.3 Tourism-facilities (ecotourism)	No	Possible	5/10	**40**	**100**
5.4 Reforestation (future forest area changes)	Stable		5/10		
					257
				Status score:	**500**

DATA RECORD SHEET **VILLAGE NO 2**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	66	MgC/ha	9/10		
1.2 Water supply	No		1/10	12	40
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	239	g	1/5	30	100
1.3.2 Frequency to find CWD or fallen branches	103	(no unit)	1/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	35	species	6/10		
2.1.2 Forest patch shape	Elongated		5/10		
2.1.3 Forest structure				21	70
2.1.3.1 DBH class 4.5–15 cm	53	%	5/5		
2.1.3.2 DBH class > 15–25 cm	32	%	5/5	30	100
DBH class > 25–35 cm	11	%			
DBH class > 35–45 cm	3	%			
DBH class > 45 cm	2	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	91	species	7/10	14	47
3.2 Raw materials (number of tree species)	16	species	2/10		
3.3 Medicinal resources	5	species	5/10	30	100
4. Information functions					
4.1 Aesthetic information (number of sceneries)	0	scenery(ies)	1/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	No	Possible	3/5	11	37
4.2.1 Research (number of research projects)	0	project(s)	1/5		
4.3 Cultural creation				30	100
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Moderately strict		3/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	No		5/10	25	63
5.2 Transportation (occurrence of small pathways)	Yes		10/10		
5.3 Tourism-facilities (ecotourism)	No	Possible	5/10	40	100
5.4 Reforestation (future forest area changes)	Stable		5/10		
				Status score:	257 / 500

DATA RECORD SHEET **VILLAGE NO 3**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	14	MgC/ha	2/10		
1.2 Water supply	Yes	Yes	10/10	18	60
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	325	g	3/5	30	100
1.3.2 Frequency to find CWD or fallen branches	139	(no unit)	3/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	50	species	9/10		
2.1.2 Forest patch shape	Circular		10/10		
2.1.3 Forest structure				21	70
2.1.3.1 DBH class 4.5–15 cm	90	%	1/5		
2.1.3.2 DBH class > 15–25 cm	8	%	1/5	30	100
DBH class > 25–35 cm	2	%			
DBH class > 35–45 cm	0	%			
DBH class > 45 cm	0	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	111	species	8/10	14	47
3.2 Raw materials (number of tree species)	14	species	2/10		
3.3 Medicinal resources	4	species	4/10	30	100
4. Information functions					
4.1 Aesthetic information (number of sceneries)	1	scenery(ies)	5/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	Yes		5/5	21	70
4.2.1 Research (number of research projects)	1	project(s)	3/5		
4.3 Cultural creation				30	100
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Very strict		5/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	Yes		10/10	30	75
5.2 Transportation (occurrence of small pathways)	Yes		10/10		
5.3 Tourism-facilities (ecotourism)	No	Possible	5/10	40	100
5.4 Reforestation (future forest area changes)	Stable		5/10		
				Status score:	**322** / **500**

DATA RECORD SHEET **VILLAGE NO 4**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	45	MgC/ha	6/10		
1.2 Water supply	No		1/10	9	30
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	217	g	1/5	30	100
1.3.2 Frequency to find CWD or fallen branches	83	(no unit)	1/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	30	species	5/10		
2.1.2 Forest patch shape	Elongated		5/10		
2.1.3 Forest structure				16	53
2.1.3.1 DBH class 4.5–15 cm	68	%	3/5		
2.1.3.2 DBH class > 15–25 cm	25	%	3/5	30	100
DBH class > 25–35 cm	8	%			
DBH class > 35–45 cm	0	%			
DBH class > 45 cm	0	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	78	species	6/10	11	37
3.2 Raw materials (number of tree species)	17	species	3/10		
3.3 Medicinal resources	2	species	2/10	30	100
4. Information functions					
4.1 Aesthetic information (number of sceneries)	2	scenery(ies)	10/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	Yes		5/5	20	67
4.2.1 Research (number of research projects)	0	project(s)	1/5		
4.3 Cultural creation				30	100
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Not strict		1/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	No		*7/10	27	68
5.2 Transportation (occurrence of small pathways)	Yes		10/10		
5.3 Tourism-facilities (ecotourism)	No	Possible	5/10	40	100
5.4 Reforestation (future forest area changes)	Stable		5/10		
				Status score:	255 / 500

*The area where a dhamma retreat is located was not declared as a community forest, but the villagers had a plan to declare this area to be a community forest in the future. Therefore, this 'habitation' function was scored at 7 which is in between 'nonoccurrence' and 'occurrence'.

DATA RECORD SHEET **VILLAGE NO 5**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	62	MgC/ha	8/10		
1.2 Water supply	Yes	No	5/10	15/30	50/100
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	292	g	1/5		
1.3.2 Frequency to find CWD or fallen branches	43	(no unit)	1/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	44	species	8/10		
2.1.2 Forest patch shape	Peninsular		1/10		
2.1.3 Forest structure				19/30	63/100
2.1.3.1 DBH class 4.5–15 cm	63	%	5/5		
2.1.3.2 DBH class > 15–25 cm	29	%	5/5		
DBH class > 25–35 cm	5	%			
DBH class > 35–45 cm	3	%			
DBH class > 45 cm	0	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	89	species	6/10		
3.2 Raw materials (number of tree species)	10	species	2/10	9/30	30/100
3.3 Medicinal resources	0	species	1/10		
4. Information functions					
4.1 Aesthetic information (number of sceneries)	1	scenery(ies)	5/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	No	Possible	3/5	15/30	50/100
4.2.1 Research (number of research projects)	1	project(s)	3/5		
4.3 Cultural creation					
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Not strict		1/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	No		5/10		
5.2 Transportation (occurrence of small pathways)	No		5/10	25/40	63/100
5.3 Tourism-facilities (ecotourism)	No	Possible	5/10		
5.4 Reforestation (future forest area changes)	Increase		10/10		
				Status score:	**256/500**

DATA RECORD SHEET **VILLAGE NO 6**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	41	MgC/ha	6/10		
1.2 Water supply	No		1/10	**11**	**37**
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	421	g	3/5	**30**	**100**
1.3.2 Frequency to find CWD or fallen branches	53	(no unit)	1/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	30	species	5/10		
2.1.2 Forest patch shape	Elongated		5/10		
2.1.3 Forest structure				**16**	**53**
2.1.3.1 DBH class 4.5–15 cm	66	%	3/5		
2.1.3.2 DBH class > 15–25 cm	27	%	3/5	**30**	**100**
DBH class > 25–35 cm	4	%			
DBH class > 35–45 cm	4	%			
DBH class > 45 cm	0	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	69	species	5/10	**10**	**33**
3.2 Raw materials (number of tree species)	11	species	2/10		
3.3 Medicinal resources	3	species	3/10	**30**	**100**
4. Information functions					
4.1 Aesthetic information (number of sceneries)	1	scenery(ies)	5/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	Yes		5/5	**17**	**57**
4.2.1 Research (number of research projects)	1	project(s)	3/5		
4.3 Cultural creation				**30**	**100**
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Not strict		1/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	No		5/10	**21**	**53**
5.2 Transportation (occurrence of small pathways)	Yes		10/10		
5.3 Tourism-facilities (ecotourism)	No	Not possible	1/10	**40**	**100**
5.4 Reforestation (future forest area changes)	Stable		5/10		
				Status score:	**233** / **500**

DATA RECORD SHEET **VILLAGE NO 7**

Selected ecosystem function(s)	Raw data record		Raw score	Total score	Calibrated total score
1. Regulation functions					
1.1 Gas regulation (aboveground carbon storage)	63	MgC/ha	8/10		
1.2 Water supply	No		1/10	17	57
1.3 Soil formation and nutrient regulation					
1.3.1 Amount of litter	430	g	3/5	30	100
1.3.2 Frequency to find CWD or fallen branches	267	(no unit)	5/5		
2. Habitat functions					
2.1 Refugee and nursery					
2.1.1 Species richness of wildlife	43	species	8/10		
2.1.2 Forest patch shape	Elongated		5/10		
2.1.3 Forest structure				23	77
2.1.3.1 DBH class 4.5–15 cm	61	%	5/5		
2.1.3.2 DBH class > 15–25 cm	25	%	5/5	30	100
DBH class > 25–35 cm	11	%			
DBH class > 35–45 cm	3	%			
DBH class > 45 cm	0	%			
3. Production functions					
3.1 Food (number of edible NTFP species)	111	species	8/10	13	43
3.2 Raw materials (number of tree species)	27	species	4/10		
3.3 Medicinal resources	1	species	1/10	30	100
4. Information functions					
4.1 Aesthetic information (number of sceneries)	0	scenery(ies)	1/10		
4.2 Research and education					
4.2.1 Nature trail (unofficial)	No	Possible	3/5	9	30
4.2.1 Research (number of research projects)	0	project(s)	1/5		
4.3 Cultural creation				30	100
4.3.1 CFM rules and regulations	Yes	No	3/5		
4.3.2 Enforcement of CFM rules and regulations	Not strict		1/5		
5. Carrier functions					
5.1 Habitation (occurrence of a dhamma retreat)	Yes		10/10	35	88
5.2 Transportation (occurrence of small pathways)	Yes		10/10		
5.3 Tourism-facilities (ecotourism)	No	Possible	5/10	40	100
5.4 Reforestation (future forest area changes)	Increase		10/10		
				Status score:	295 / 500

Appendix 11: Full description of the first model.

Overview

The first model description implemented as an initial RPG is written based on the ODD protocol (Grimm *et al*., 2006; 2010). The purposes of this model are to validate a shared understanding on NTFP dynamics in relation to harvesters' behaviour and explore feasible scenario(s) for sustainable management of NTFPs with local stakeholders.

Entities

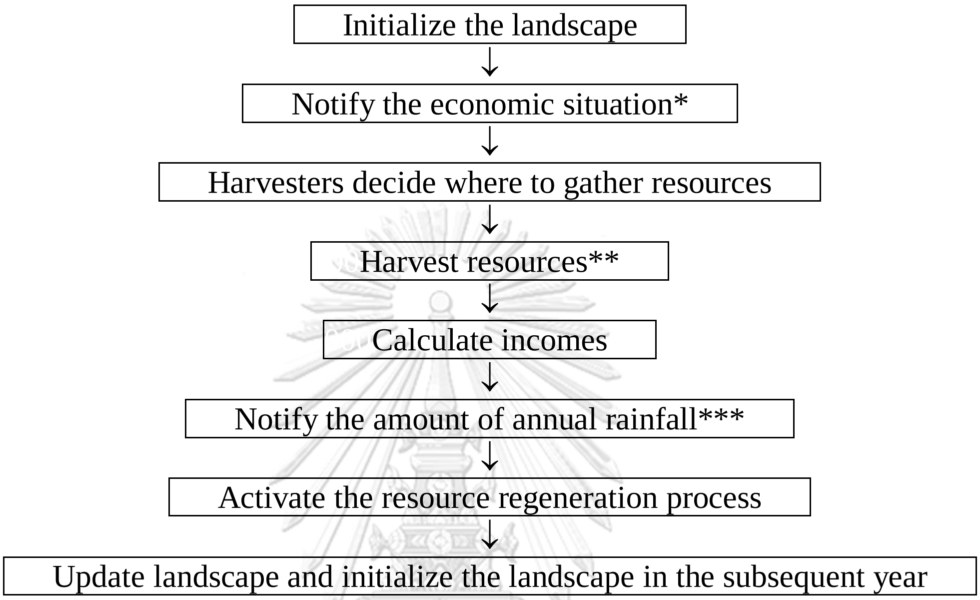
Community forest microhabitat: the abstract landscape is a spatial grid of 25 cells representing a 400 ha community forest with spatially distributed heterogeneous NTFP resources. These resources are the three major NTFPs commonly found in the region: (i) young shoots of *Melientha suavis*, (ii) queen broods of *Oecophylla smaragdina* (weaver ant), and (iii) wild edible mushrooms (Wimolsakcharoen *et al*., 2020). Each cell bears a given amount of available resources set at one of four levels as follows: 0 (no resource), 1 (low amount of resources), 2 (medium amount of resources), and 3 (high amount of resources). The resource capacity (i.e. the maximum level of available resources) varies among these cells due to the heterogeneity of habitats in the landscape. In other words, diverse microenvironment conditions (resulting mainly here from different tree compositions) in the community forests influenced the capacity of the forest habitat to provide NTFP resources (Burton and Eggleton, 2016).

Local resource harvesters: the number of harvesting agents ranges from 14 to 20, and there are three types of harvesting agents, as follows: (i) landless villager, (ii) small and medium landholders, and (iii) larger landholders.

Market: this entity buys the resources from the harvesters. The farm gate price of each kind of NTFPs is agreed upon by the players at the beginning of the first gaming session and this price remains constant throughout the successive rounds of play and the following gaming session.

Process overview and scheduling

One round of play corresponds to one year and a gaming session is composed of at least two successive years. The scheduling of the eight successive steps in each round of play is shown in Figure A.1.



*Starting at the beginning of the second round of the first session onwards.
**Landless villager, small and medium landholders, and larger landholders are allowed to harvest resources three times, twice, and only once in each round of play, respectively.
***The initial amount of annual rainfall of each gaming session is always defined as ‘normal’.

Figure A.1: Scheduling of the successive steps in a year simulated by the first model implemented as an initial RPG.

Design concepts

The Resource and Habitat (ReHab) gaming and simulation tool supported by a computer ABM (Le Page *et al*., 2016) was used as an inspiring prototype to build this model. The following three complementary theoretical concepts were mobilized in the model design phase.

Common-pool resources: correspond to renewable resources in a natural ecosystem which are open-access for anyone to use. There is no owner of these resources and appropriators harvesting them gain property rights only on what they harvest. (Hess and Ostrom, 2003).

Adaptive management and capacity: a learning-based approach involving the fundamental features of learning and adaptation which leads to an improved understanding of the resource system and its dynamics, and improved management based on that understanding (Williams, 2011). The concept of adaptive capacity, which reflects learning and ability of groups to act collectively during a crisis or surprise in order to experiment and foster innovative solutions in a SES, can be used to examine common-pool resource management challenges (Armitage, 2005; Cundill and Fabricius, 2010).

Adaptive co-management: a flexible governance-based approach to common-pool resource management tailored to specific places and situations. It combines the learning-by-doing approach of adaptive management with the collaborative approach of co-management (Armitage *et al*., 2009; Schultz *et al*., 2011).

Implementation details

Initialization

The initial configuration of the spatial distribution of both resource potentials (Figure A.2a) and resource levels (Figure A.2b) among the cells of the model's main interface is always the same at the start of a gaming session. The initial resource carrying capacity of the landscape (its total resource potential) corresponds to 60 resource units defined by the number of cells bearing a given resource level [(**3** × 10)[8] + (**2** × 15) + (**1** × 0) + (**0** × 0) = 60], as displayed in Figure A.2a. The initial resource availability always accounts for half of the carrying capacity as follows: (**3** × 3) + (**2** × 5) + (**1** × 11) + (**0** × 6) = 30 resource units (see in Figure A.2b).

[8](3 × 10) means that 10 cells have a resource level equal to 3.

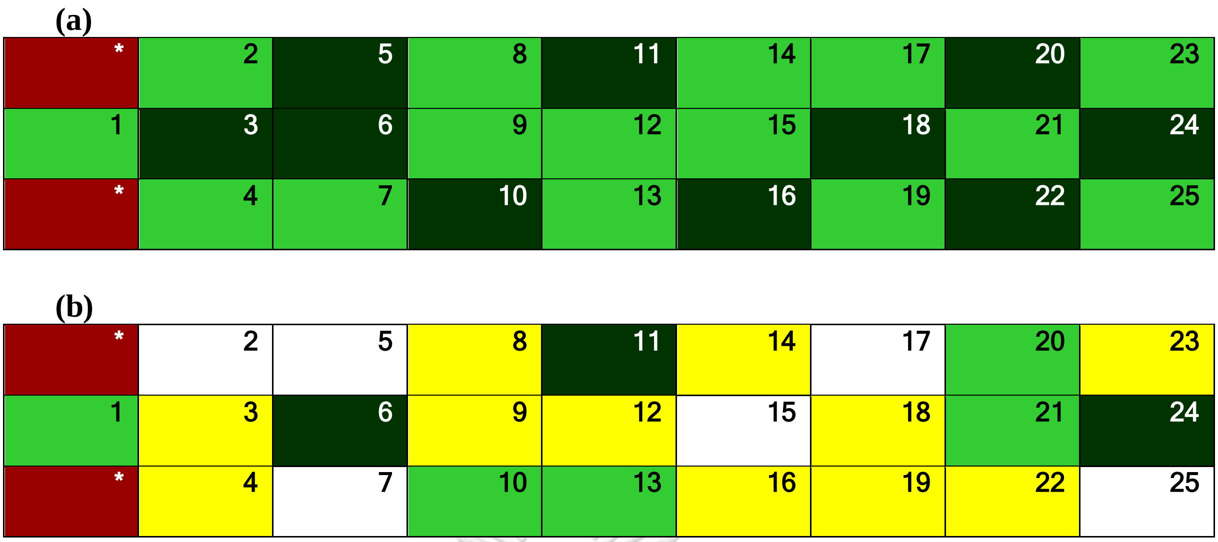


Figure A.2: (a) Spatial distribution of the initial resource potential on the interface of the first model implemented as a RPG. Different colors indicate different resource potentials: only level 2 (green), and level 3 (dark green) appear at the initialization stage. (b) Initial spatial configuration of the resource levels on the grid of the first model at the beginning of a gaming session. Different colours indicate different levels of available resources: level 0 (white), level 1 (yellow), level 2 (green), and level 3 (dark green). The two brown cells marked by an asterisk (*) to the left were designed in case the participants would propose to expand the area of their community forests.

Input data

Data on the actual annual production of the three major kinds of NTFPs in the community forests of Lainan Subdistrict obtained during the initial field investigations were used to determine the quantity of resources available in the landscape (Table A.1). This model also requires input data to select the location of the local resource harvesters.

Table A.1: Amount of resources corresponding to the different resource levels (RL).

Resource	Amount of resources (kg)			
	RL 0 (white)	RL 1 (yellow)	RL 2 (green)	RL 3 (dark green)
Melientha suavis	0	10	20	30
Oecophylla smaragdina's queen brood	0	25	50	75
Edible mushrooms	0	10	20	30

Sub-models

Resource harvesting: based on the previous ecological field studies in the preliminary diagnostic phase, the possible amount of resources harvested by each local resource harvester is as follows:

- *M. suavis:* maximum 30 kg/harvester/round
- *O. smaragdina*'s queen brood: maximum 90 kg/harvester/round
- Edible mushrooms: maximum 30 kg/harvester/round

These harvested resource quantities are doubled for the small and medium landholders, and tripled for the landless villager due to the different number of times allowed them gathering the resources in the landscape in each round of play. At the village level, the amount of available resources in the community forests of each village is different, so the cumulated amount of resources gathered by all harvesters from the same village is also limited, as shown in Table A.2.

Table A.2: Collective amount of resources allowed to be gathered in each round of play.

Type of resources	Maximum cumulated amount of harvested resources in each village (kg/village/round)						
	V1	V2	V3	V4	V5	V6	V7
Melientha suavis	120	150	250	10	30	20	20
Oecophylla smaragdina's queen brood	600	2,800	200	0	0	0	0
Edible mushrooms	40	100	300	30	30	40	60

Influence of the amount of annual rainfall on the resource regeneration: in each round of play, the amount of annual rainfall influences the resource regeneration process. High amount of annual rainfall increases the resource level by one unit, whereas low amount of annual rainfall decreases the resource level by one unit. The resource level does not change when the amount of annual rainfall is normal, as shown in Figure A.3.

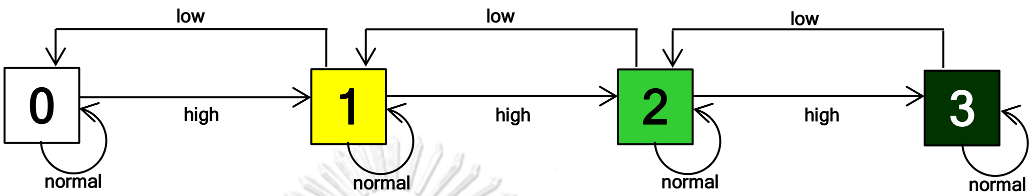


Figure A.3: State-transition diagram of the resource level dynamics according to the amount of annual rainfall.

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Appendix 12: Full description of the CoComForest model.

Overview

This model description is written based on the ODD protocol (Grimm *et al*., 2006; 2010), and is named 'CoComForest', standing for COllaborative COMmunity FOREST management. The purposes of this model are to (i) represent the proposed scenarios received from using the first model with local people in the first participatory modelling and simulation sequence, (ii) explore additional scenario(s) (if any), and (iii) promote exchange of knowledge, perceptions, and experiences among local stakeholders in order to find collective agreement on CFM at the subdistrict scale.

Entities

Community forest microhabitat: the abstract landscape is a spatial grid of 25 cells (5 × 5) representing a 400 ha community forest with spatially distributed heterogeneous NTFP resources. These resources are the three major NTFPs commonly found in the region: (i) young shoots of *Melientha suavis*, (ii) queen broods of *Oecophylla smaragdina* (weaver ant), and (iii) wild edible mushrooms (Wimolsakcharoen *et al*., 2020). Each cell bears a given amount of available resources set at one of five levels as follows: 0 (no resource), 1 (low amount of resources), 2 (medium amount of resources), 3 (high amount of resources), and 4 (very high amount of resources). The resource capacity (i.e. the maximum level of available resources) varies among these cells due to the heterogeneity of habitats in the landscape. In other words, diverse environmental conditions (resulting mainly here from different tree compositions) in the community forests influenced the capacity of the forest habitat to provide NTFP resources (Burton and Eggleton, 2016).

Resource harvesters: the number of harvesting agents ranges from 20 to 30, and there are two main types of harvesting agents, as follows:

(i) local harvesters from the Lainan Subdistrict; and

(ii) outsiders from other subdistricts or even other provinces. The local stakeholders requested to introduce this second type of harvester in the cRPG tool after the initial gaming session.

Market: this entity buys the resources from the harvesters. The farm gate price of each kind of NTFP is agreed upon by the harvesters at the beginning of the first gaming and simulation session and this price remains constant throughout the successive rounds of play and the following sessions.

Firebreak: the addition of this passive entity was requested by the local stakeholders when they first used the initial model as a gaming tool. Wildfire regularly occurs in warm and dry season (March and April) in these deciduous community forests and the establishment of firebreaks is seen as an effective and low-cost way to prevent its spreading and damages. In the gaming and simulation sessions, the decisions to establish firebreaks and their locations in the landscape rely on a collective agreement among the local harvesters. This option was available in all rounds of the second and third sessions of the participatory gaming and simulation workshop. The resource capacity of a cell equipped with a firebreak increases by one unit because the local stakeholders consider that the potential production of NTFPs is improved by the prevention of wildfire damage. This allows some cells to display the maximum level (4) of resource availability.

Process overview and scheduling

One round of play corresponds to one year and a gaming and simulation session is composed of at least three successive years. The scheduling of the seven successive steps in each round of play is shown in Figure A.4.

Initialize the landscape
↓
Firebreak establishment*
↓
Harvesters decide where to gather resources**
↓
Harvest resources
↓
Record harvested resource units and calculate incomes
↓
Activate the resource regeneration process
↓
Update landscape and initialize the landscape in the subsequent year

*Starting at the beginning of the first round of the second session onwards.
**The decision about where outsiders gather NTFP resources was activated in the third session.

Figure A.4: Scheduling of the successive steps in a year simulated by the CoComForest model.

Design concepts

Initially, the design of the CoComForest model was inspired by the Resource and Habitat (ReHab) gaming and simulation tool supported by a computer ABM (Le Page *et al*., 2016). The following three complementary theoretical concepts were mobilized in the model design phase.

(i) *Common-pool resources:* correspond to renewable resources in a natural ecosystem that are open-access for anyone to use. There is no owner of the resources and appropriators harvesting them gain property rights only on what they harvest (Hess and Ostrom, 2003).

(ii) *Adaptive management and capacity:* a learning-based approach involving the fundamental features of learning and adaptation that leads to an improved understanding of the resource system and its dynamics, and an improved management based on that understanding (Williams, 2011). The concept of adaptive capacity, which reflects learning and the ability of groups to act collectively during a crisis or surprise in order to experiment and foster innovative solutions in a SES, can be used to examine common-pool resource management challenges (Armitage, 2005; Cundill and Fabricius, 2010).

(iii) *Adaptive co-management*: a flexible governance-based approach to common-pool resource management tailored to specific places and situations. It combines the learning-by-doing approach of adaptive management with the collaborative approach of co-management (Armitage *et al*., 2009; Schultz *et al*., 2011).

Implementation details

Initialization

The initial configuration of the spatial distribution of both resource potentials (Figure A.5a) and resource levels (Figure A.5b) among the cells of the model's main interface is always the same at the start of a gaming and simulation session. The initial resource carrying capacity of the landscape (its total resource potential) corresponds to 60 resource units defined by the number of cells bearing a given resource level [(**3** × 10)[9] + (**2** × 15) + (**1** × 0) + (**0** × 0) = 60], as displayed in Figure A.5a. There is no cell with resource level 4 at the initial stage as this maximum level depends on human intervention to prevent wildfire damages by establishing firebreaks. The initial resource availability always accounts for half of the carrying capacity as follows: (**3** × 3) + (**2** × 5) + (**1** × 11) + (**0** × 6) = 30 resource units (see in Figure A.5b).

[9] (3 × 10) means that 10 cells have a resource level equal to 3.

(a)

(b)

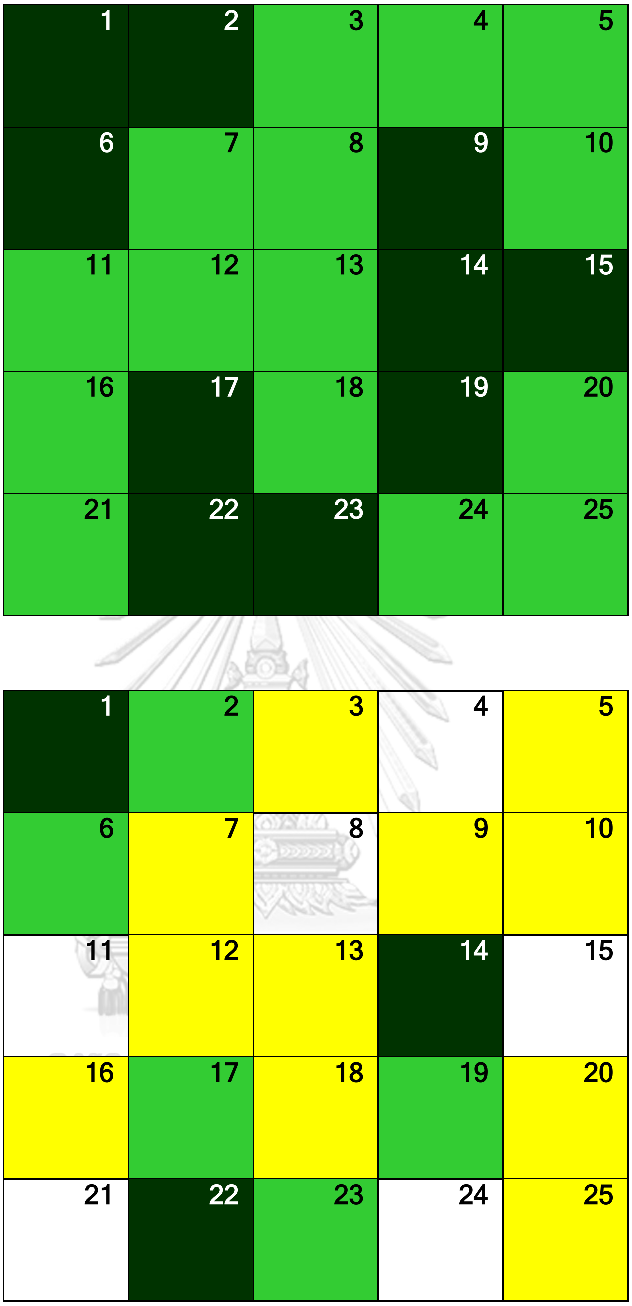

Figure A.5: (a) Spatial distribution of the initial resource potential on the interface of the CoComForest model. Different colors indicate different resource potentials: only level 2 (green) and level 3 (dark green) appear at the initialization stage. (b) Initial spatial configuration of the resource levels on the grid of the CoComForest model at the beginning of a gaming and simulation session. Different colors indicate different levels of available resources: level 0 (white), level 1 (yellow), level 2 (green), and level 3 (dark green).

Input data

Data on the actual annual production of the three major kinds of NTFPs in the community forests of Lainan Subdistrict obtained during the initial field investigations were used to determine the quantity of resources available in the landscape in the absence of any firebreak (Table A.3). When a firebreak is established, the annual production of all three major NTFPs doubles to reflect the increased production potential of the cell, as shown in Table A.3. This increase was decided through a collective agreement of the participants based on their experience and the use of the first model as an initial RPG in the co-design phase.

This model also required input data to select the location of the harvesters. In each round of play of a gaming and simulation session, the harvesters decide on which cell of the landscape they prefer to gather resources and the model registers their location year by year.

Table A.3: Amount of resources without and equipped with firebreak establishment corresponding to each resource level (RL).

Resource	Firebreak establishment	Amount of resources (kg)				
		RL 0 (white)	**RL 1 (yellow)**	**RL 2 (green)**	**RL 3 (dark green)**	**RL 4 (blue)**
Melientha suavis	No	0	10	20	30	n/a
	Yes	0	20	40	60	80
Oecophylla smaragdina's queen brood	No	0	25	50	75	n/a
	Yes	0	50	100	150	200
Edible mushrooms	No	0	10	20	30	n/a
	Yes	0	20	40	60	80

Sub-models

(i) *Resource harvesting:* a local harvester or an outsider can gather resources in only one cell in a given round of play. If several agents visit the same cell, the available resource units are randomly allocated among them based on the probabilities shown in Table A.4.

Table A.4: Sharing of the resources when more than one harvester is located on a cell in the same round of play.

No. of agents	Resource level	Probability (%)	Sharing of the resource units among harvesters				
			Agent 1	Agent 2	Agent 3	Agent 4	Agent 5 onwards
>=4	4	55	1	1	1	1	0
		20	2	1	1	0	0
		10	2	2	0	0	0
		10	3	1	0	0	0
		5	4	0	0	0	0
	3	85	1	1	1	0	0
		10	2	1	0	0	0
		5	3	0	0	0	0
	2	95	1	1	0	0	0
		5	2	0	0	0	0
	1	100	1	0	0	0	0
3	4	50	2	1	1	n/a	n/a
		20	2	2	0	n/a	n/a
		20	3	1	0	n/a	n/a
		10	4	0	0	n/a	n/a
	3	70	1	1	1	n/a	n/a
		20	2	1	0	n/a	n/a
		10	3	0	0	n/a	n/a
	2	90	1	1	0	n/a	n/a
		10	2	0	0	n/a	n/a
	1	100	1	0	0	n/a	n/a
2	4	40	2	2	n/a	n/a	n/a
		40	3	1	n/a	n/a	n/a
		20	4	0	n/a	n/a	n/a
	3	80	2	1	n/a	n/a	n/a
		20	3	0	n/a	n/a	n/a
	2	80	1	1	n/a	n/a	n/a
		20	2	0	n/a	n/a	n/a
	1	100	2	0	n/a	n/a	n/a
Single agent	1–4	100	1–4	n/a	n/a	n/a	n/a

(ii) *Influence of visiting harvesters on resource regeneration:* in each round of play, the total number of visiting harvesters on a cell influences the resource regeneration process. Based on the information gathered during the preliminary field investigations, the author considered that damages occur occasionally due to the harmful harvesting practices of outsiders (Wimolsakcharoen *et al*., 2020). Therefore, when outsiders visit a cell, its resource level decreases to zero. In the case of different local harvesters visiting the same cell, their number affects the subsequent resource level as shown in Figure A.6 and outlined as follows:

(a) When the number of visiting local harvesters is higher than two, the resource level decreases to zero.

(b) When there are two local harvesters visiting the cell, its resource level decreases by one unit.

(c) The resource level increases when there are no visiting local harvesters, and it does not change when only one local harvester visits the cell.

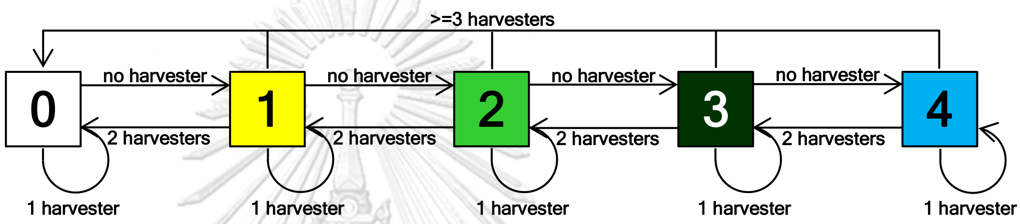

Figure A.6: State-transition diagram of the resource level dynamics according to the number of visiting local harvesters on a given cell.

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VITA

NAME	Wuthiwong Wimolsakcharoen
DATE OF BIRTH	3 January 1990
PLACE OF BIRTH	Bangkok
INSTITUTIONS ATTENDED	Bachelor of Science in Biology with Honors in 2011 from the Faculty of Science, Chulalongkorn University, Thailand.
PUBLICATION	Wimolsakcharoen, W., Dumrongrojwatthana, P., and Trébuil, G. 2020. Production of non-timber forest products (NTFPs) and diversity of harvesters' practices and decision-making processes in northern Thailand community forests. Bois et Forêts des Tropiques 343: 39–52.