Ecosystems and Development Journal

Volume 13 • Number 1 • 2023

ISSN 2782-8824 (online)
ISSN 2012-3612 (print)

College of Forestry and Natural Resources
University of the Philippines Los Baños

Ecosystems and Development Journal

A Journal on Tropical Forests, Ecosystems, and Natural Resources

Volume 13 No. 1 2023

The cover features the *Madhuca betis* tree from Makiling Botanic Gardens, Mount Makiling Forest Reserve, Philippines. It is a species indigenous to Indonesia and the Philippines, currently designated as "Vulnerable" by the IUCN Red List.

Photo by Dr. Manuel L. Castillo

About the Journal

Ecosystems and Development Journal is an international refereed journal that aims to help promote science-based policies and decisions in the management and conservation of forests and other ecosystems towards sustainable development through dissemination and exchange of related research results, concepts, methods, policies, and practices. It is published at least once a year by the College of Forestry and Natural Resources (CFNR), University of the Philippines Los Baños (UPLB). E&D Journal can be accessed online through www.edjournal.cfnr-uplb.org.

The E&D Journal accepts research and policy papers, research notes, concept papers, and scientific review papers on forests and other ecosystems, and its interactions with physical and human systems in general and with development in particular.

Please refer to the E&D Journal Guide to Authors for proper formatting of submitted articles.

For submission of manuscript, address to:

The Editor-in-Chief
Ecosystems and Development Journal
Office of the Coordinator for Research, Extension,
and Linkages, College of Forestry and Natural Resources
University of the Philippines Los Baños
College, Los Baños, Laguna
Email: edjournal@up.edu.ph

E&D Journal Editorial Staff

The Ecosystems and Development Journal expresses its sincere appreciation to the following experts for reviewing the papers submitted in this issue.

LIST OF REVIEWERS

Dr. Amalia E. Almazol*, Professor, Department of Forestry and Environmental Science, College of Agriculture, Southern Luzon State University, Lucban, Quezon, Philippines*

Asst. Prof. Juancho B. Balatibat*, Assistant Professor, Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

For. Leonardo D. Barua*, Researcher, Makiling Center for Mountain Ecosystems, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Asst. Prof. Marjorie D. delos Angeles*, Assistant Professor, Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Jose Nestor M. Garcia*, Retired Faculty Member, Agricultural Systems Institute, College of Agriculture and Food Science, University of the Philippines Los Baños, College, Laguna, Philippines*

Asst. Prof. Neil Jun S. Lobite*, Assistant Professor, Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Roscinto Ian C. Lumbres*, Professor, College of Forestry, Benguet State University, La Trinidad, Benguet, Philippines*

Dr. Catherine C. De Luna*, Researcher, Integrated Natural Resources and Environment Management, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Rose Jane J. Peras*, Professor, Department of Social Forestry and Forest Governance, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Tomas D. Reyes, Jr.*, Associate Professor, Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Cristino L. Tiburan, Jr.*, Professor, Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Crusty E. Tinio*, Associate Professor, Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Asst. Prof. Arthur Glenn A. Umali*, Assistant Professor, Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

Dr. Arvin P. Vallesteros*, Professor, College of Forestry, Environmental and Resource Management, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines*

Dr. Rosario Velasco-Tatlonghari*, Assistant Professor, Department of Science Communication, Institute of Renewable Natural Resources, College of Development Communication, University of the Philippines Los Baños, College, Laguna, Philippines*

Table of Contents

p-ISSN 2012-3612 | e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 | Number 1 | pp. 1–16 | 2023

Typology of agroforestry practices, perceived benefits, and challenges: The case of Kapit-Bisig Farmer's Association Inc., Barangay Sta. Catalina, Atimonan, Quezon, Philippines

Rhyla Joy M. Aldipollo[1*], Lorena L. Sabino[2], Elsa P. Santos[2]

[1]*Urban and Biodiversity Research, Development and Extension Center, Ecosystems Research and Development Bureau, Laguna, Philippines;*
[2]*Department of Social Forestry and Forest Governance, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. This study examined the perceived benefits and challenges of agroforestry technologies adopted by the Kapit-Bisig Farmer's Association Incorporated (KBFAI) members in Barangay Sta. Catalina, Atimonan, Quezon. The association was established in 1989 and became a partner organization of the Department of Environment and Natural Resources (DENR) to implement the Community-Based Forest Management (CBFM) program, including agroforestry, in 1997. In 2018, the KBFAI was awarded the Best CBFM Model in the CALABARZON region. All 50 active members interviewed adopted the multi-storey agroforestry system, which provided farmers with economic benefits, such as a variety of produce, better yield, and regular monthly income. Some respondents' farmers integrated forest/fruit trees and crops, poultry, livestock, and apiculture into their farms. Socially, the KBFAI encouraged members to participate in various organizational, technical, and life skills training initiated by linked government agencies. Livelihood skills augmented members' income through the "*coprahan*" venture, selling seedlings from their nursery, rattan basket weaving, and tiger grass broom making, where raw materials were sourced from the CBFMA area. The training also sensitized them to avoid traditional livelihood activities, such as *kaingin* and charcoal making. Members likewise enjoyed the environmental benefits of their agroforestry farms through soil improvement, shade to crops, sustained water supply, and reduced soil erosion in steep slopes. Despite these benefits and improved well-being, findings showed that farmers' continued adoption of agroforestry was uncertain as most members became senior citizens and had difficulty maintaining their agroforestry farms. Their children were hardly interested in farming. This study recommends that the DENR and support organizations incentivize agroforestry farming to attract and engage the young generation and sustain the beneficial agroforestry systems in Barangay Sta. Catalina and in all uplands nationwide.

Keywords: Aging farmers, agroforestry technologies, community-based forest management, ecologically sustainable, upland farming

Article Information
Received 15 October 2022
Accepted 26 May 2023
Published online 16 October 2023
*Email: rmaldipollo@up.edu.ph

INTRODUCTION

Kaingin and charcoal production are the major threats to the last remaining patches of the Philippines rainforest (Meeteren, 2012). Most residents of Barangay Sta. Catalina, Atimonan, Quezon practiced such activities in the 1980s as their traditional means of livelihood. The government encouraged the residents to adopt agroforestry technologies to supplant their destructive activities when the former introduced the Integrated Social Forestry (ISF) Program in 1984. Members of the Samahang Pangkaunlaran ng Bantakay, the precursor of the Kapit-Bisig Farmer's Association Incorporated (KBFAI), participated in the ISF Program and became recipients of the Certificate of Stewardship Contract (CSC). Individual farmers were recognized as potential government partners in sustainable upland farming. They were given 4 to 7 ha of timberland, which they could use as food production areas, provided that 20% of the stewarded area be planted to timber species or fruit trees. The contract has 25 years term, renewable for another 25 years upon agreeable land use.

In 1989, the KBFAI was established and registered on August 7, 1991, with the Securities and Exchange Commission. KBFAI became a recipient of the Community-Based Forest Management (CBFM) program of the Department of Environment and Natural Resources (DENR) on June 27, 1997. As DENR's partner in managing, improving, protecting, and wise utilization of natural resources, KBFAI was awarded 2,207.30 ha of timberland in Barangay Sta. Catalina, Atimonan, Quezon. The timberland is under a CBFM Agreement good for 25 years but may be renewed if KBFAI proves to be a trustworthy partner of the DENR. The concept underlying CBFM is that communities participating in decision-making are in the best position to manage and protect forests sustainably (Duthy & Bolo-Duthy, 2003).

Initially, there were 331 legitimate members of KBFAI. Membership sharply decreased before 2000 and stabilized at slightly less than 100 by 2010. KBFAI was a well-known CBFM Agreement holder in the Philippines engaged in different DENR-supported activities to conserve timberlands. Through agroforestry adoption, it trains other communities to strengthen their organization and improve their upland farms. In 2012, it was recognized by the DENR for its "Good CBFM Practice," and in 2018, it was awarded the "Best CBFM Model in the CALABARZON region."

Agroforestry is a concept that has been introduced in the Philippines. Members of KBFAI adopted agroforestry systems that could alleviate their well-being. Since the 1960s, smallholder farmers have traditionally raised trees, crops, and animals. However, their integrated farming system was abandoned as they shifted to modern agriculture focused on monocropping using commodity crops for exports, such as coconut, rice, and banana. Before adopting agroforestry, upland farmers in the study area had cultivated rice. However, using expensive external farm inputs, such as fertilizer, seeds, and pesticides, was difficult to sustain because of meager capital resources. Continuous application of fertilizer led to soil acidity. Growing a single crop increases the risk of failure due to unproductive soil and increasing pest and disease occurrences. Intensive farming, declining farm productivity, and increasing indebtedness posed a disturbing challenge to the upland farmers of Sta. Catalina. Some farmers have yet to know about sustainable upland farming, like agroforestry.

After being introduced to agroforestry technologies in the early 1980s, KBFAI farmers continued to practice agroforestry. After being introduced to agroforestry technologies in the early 1980s, KBFAI farmers continued to practice agroforestry. However, there was a pressing need for comprehensive documentation regarding the specific agroforestry technologies adopted, context, benefits of agroforestry to the farmers, and the various challenges they faced that constrained the continuity of the farming practice. This study examined the types of agroforestry practices of KBFAI farmers, the characteristics of these farmers, and their perceived economic, social, and environmental benefits in agroforestry technology adoption. The constraining and enabling factors in agroforestry technology adoption among the KBFAI farmers were also explored.

METHODOLOGY

Location of the study

The study was conducted in Barangay Sta. Catalina, Atimonan, Quezon, in the mid-southern part of Luzon (**Figure 1**), with a latitude of

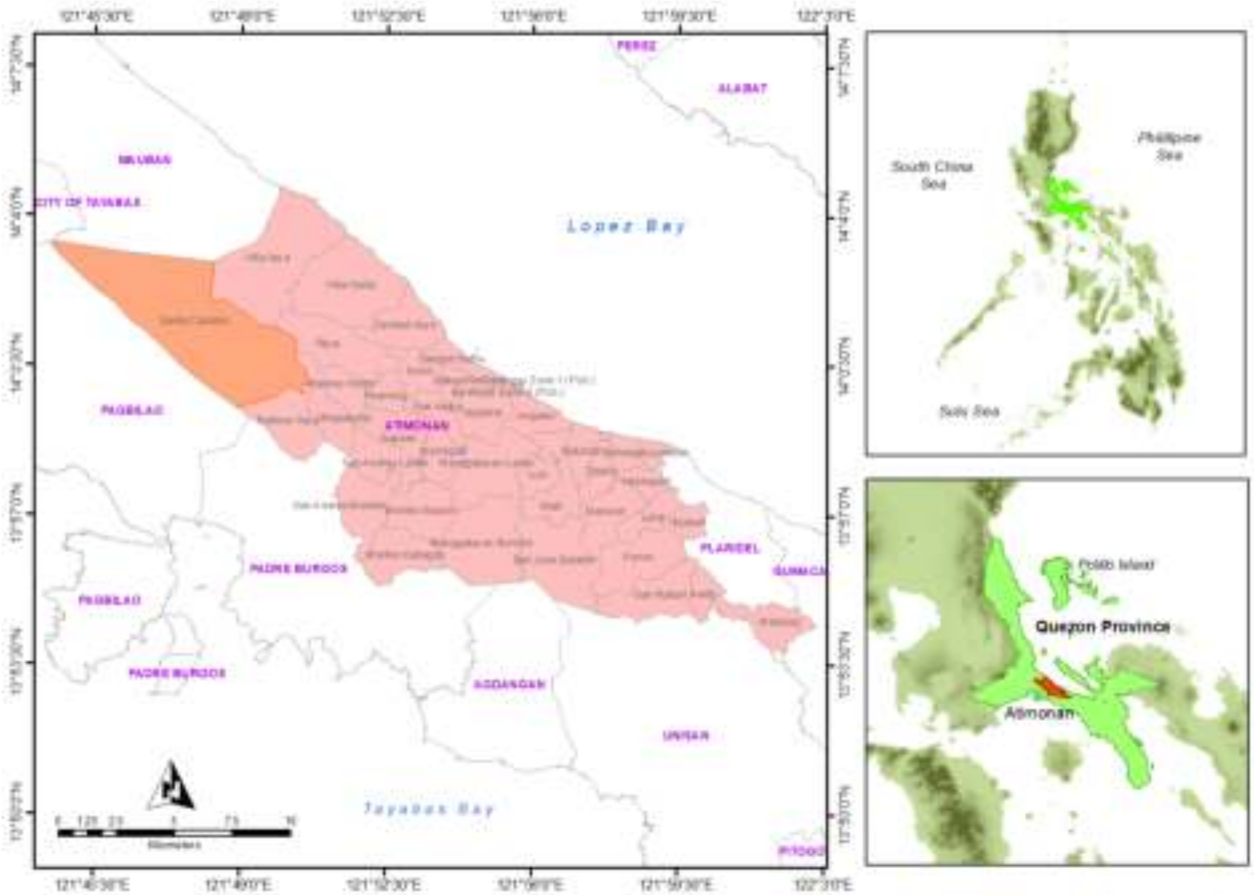


Figure 1. Study location showing Barangay Sta. Catalina.

14°1' N, a longitude of 121°48' E, and an altitude of 64 m or 121.97 ft above mean sea level (m asl). In 2020, the barangay had a population of 2,723, representing 4.24% of Atimonan (PSA, 2020). The majority of the KBFAI members resided in Sta. Catalina, particularly in Sitios Kailogan, Bantakay, Banabahan, Hubilyuhan, Gitna, and Sapinit. Some members resided in the Municipality of Pagbilao, an adjacent town of Atimonan.

KBFAI has been a recipient of various programs and projects since the 1980s. In 2004, a Regional Training Center (RTC) was constructed in Sitio Bantakay with the support of the DENR. This now serves as the venue for community training of the DENR, with KBFAI officers serving as resource persons. This center also serves as the office of KBFAI.

Research design and conceptual framework

This case study generates a thorough description of the agroforestry practices of KBFAI members through qualitative research. To collect primary data and understand agroforestry farming practices, immersion in the study site was done from June to July 2019 for continuous observation, farm visits, interviews, interaction with farmers, farm sketching, transect walk, and photo documentation. Continued stay in the area facilitated focus group discussion (FGD) with farmers and survey using a semi-structured interview schedule. Additional data was collected in September and October 2022 for validation with KBFAI leaders and photo documentation. Secondary data (mostly maps and reports) were also secured from local government units and the DENR. KBFAI was selected as the study organization since it has practiced agroforestry for over three decades. Moreover, the organization has been a long-term partner of the DENR and was recognized for its successful CBFM project implementation in 2012 and 2018.

Informed consent and permission to stay in the study site were first secured by consulting the officers of KBFAI. Other formal requests to stay in the area were sent to the concerned local government units. Field visits were made for site familiarization and to finalize the checklist of questions for the FGD and survey instrument using a semi-structured interview schedule. These visits also helped determine the type of secondary data needed. The survey interviewed 50 KBFAI members. In the FGD, all nine participants were officers of KBFAI. Data gathered were analyzed using descriptive statistics.

Agroforestry technology adoption by KBFAI members is influenced primarily by their perceived economic, social, and environmental benefits of the technology (**Figure 2**). However, this techno-adoption process is not a linear engagement. Other factors are at play in agroforestry adoption: the characteristics of the adopters, characteristics of the agroforestry system and variant technology, and the continuing challenges and enabling factors encountered during the technology adoption process.

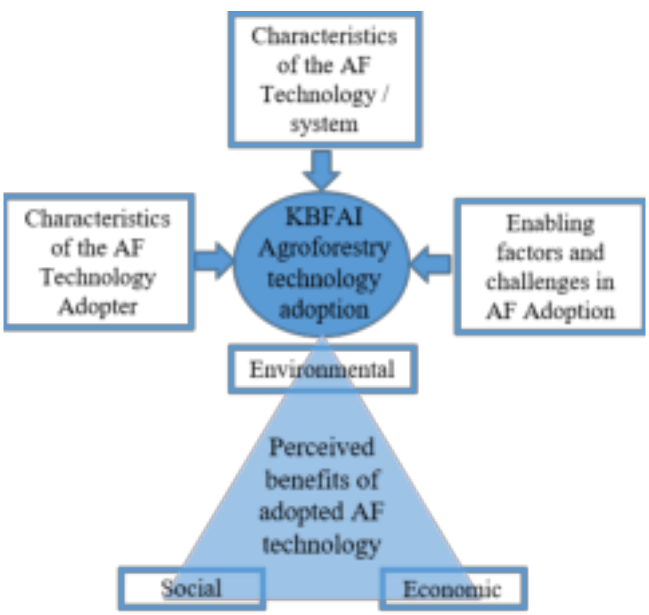


Figure 2. Conceptual framework of the study.

Sampling method

In the conduct of the survey, purposive sampling was employed. The sampling method was applied to members of KBFAI practicing agroforestry. Official membership of KBFAI was listed at 331 in 2019, but less than 10% (only 31 members) were actively participating (DENR-CENRO-Calauag, 2019). In 2020, the CBFM Compliance Monitoring Report for KBFAI of the CENRO showed the active participation of 67 members only (26 males and 41 females), approximately 20% of the total members listed (DENR-CENRO Calauag, 2020). Given the variability of active membership, it was decided to interview 50 KBFAI members, representing 70% of those in the 2020 active list or 15% of the outdated KBFAI members list. The selection was based on active membership in KBFAI and agroforestry adoption.

RESULTS AND DISCUSSION

Characteristics of KBFAI agroforestry technology adopters

Demographic characteristics

Men and women equally represented the respondents. Of the 50 active KBFAI members interviewed, the majority (40%) were middle-aged, with the range of 45-59 years, followed by senior members, 60-80 years (32%). Those between 18-25 and 26-44 years totaled 28% of respondents.

The senior members were mostly active in CBFM activities since they had ample time to attend meetings. Among the adult, active members were those who lived near the KBFAI office or in areas where the officers resided. In Sitio Hubilyuhan, the remotest village from the KBFAI office, only the president of the People's Organization (PO) attended meetings. Instead, members living far from the office preferred to wait for announcements or updates. Of the 50 respondents, 38% (19) lived in Sitio Bantakay, where the KBFAI office is located. Their proximity allowed them early and easy access to useful information, especially on income-generating opportunities. Those from two villages close to the KBFAI office – Sitio Kailogan and Sitio Sapinit – constituted 28% and 24%, respectively.

Most KBFAI respondents (28%) have five family members, and the average family size is 5.2. This is higher compared to the population census of the Philippine Statistic Authority (PSA) on the average household size in 2015 and 2020, which were 4.4 and 4.1, respectively. Such family size is considered small for an agricultural community in the Philippines, where households are usually large, owing to a greater number of children and accommodation of close relatives expected to help in the farm and livelihood activities, house chores, or errands. In terms of educational attainment, more than half of the respondents (53%) completed elementary education. Some (21%) finished high school, and only three were college graduates. Farmer respondents could read and write despite their low educational attainment, traced to the absence of schools in the area and their exposure to farming activities. Only one elementary school was found in the area; barangay high schools and colleges were absent. Poor households would be heavily indebted to put up the travel and lodging allowance if their schooling children push for higher educational pursuits. Without a scholarship or outside support, school-age children had to be content with an elementary diploma. Some children also believed that it was their duty to help their parents (this is common among the eldest child) so the family would survive. Older children may forego their dream of higher education to take care of younger siblings, especially when the family is large and secondary or tertiary schools are located several kilometers away from the house.

Each family member, whether in nuclear or extended type, was socialized to perform a function needed to maintain harmony and the structural integrity of the family as an institution. Most senior respondents mentioned that the family's survival matters most, so they spend more time producing or finding food than being educated. In Sta. Catalina uplands, farming requires adaptive skills and long experience dealing with poor soil conditions. Many were engaged in farming since childhood because this was an expected role. Farm parcels were small since the land tilled by KBFAI members was classified as timberland. Before the DENR intervention, local farmers mostly used the slash-and-burn or *kaingin* system to clear the forest vegetation. Income derived from cash crops raised on the small farm was augmented by charcoal making, a quicker way to earn cash every 15-20 days. Branches and tree trunks for charcoal production were removed from the upper slopes of Sta. Catalina and other timberlands, far from the farms. This clearing activity eventually provided additional farm parcels. So, the bigger the family, the more workers were utilized to engage in labor-intensive *kaingin* and charcoal making. More males in the family may entail higher charcoal production and, thus, higher cash income. These livelihood strategies were destructive to the forest cover of Atimonan and nearby coastal plains. Therefore, the government had to introduce agroforestry technologies and other livelihood training to help the farmers and save the forests.

Farm decisions and stewardships by gender

Regarding decision-making on farming activities, men (66%) usually decide since they are more capable of performing labor-intensive activities such as land preparation, plowing, and harrowing. The farm was the domain of married men, who were expected to be present to make the farm yield produce that may be sold for income generation. They managed and solved problems related to the farm. Women (14%) involved in farm decision-making were widows and single parents. Only seven respondents (20%) indicated that males and females managed farms together. This result is consistent with the findings of Torreta (1992) in the study site, claiming that both husbands and wives jointly made farm decisions. However, husbands did most of the strenuous activities in land and farm preparation, harvesting, and post-harvesting, livestock raising, charcoal making, and fuel wood gathering.

For land stewardship, 45 respondents (90%) have been long-time KBFAI members and were CSC recipients handed out in the early 1980s. Five were new members who applied for stewardship but had yet to obtain the stewardship tenure. Some couples, both KBFAI members, applied for separate stewardship but were given only one CSC. Torreta (1992) indicated that in 1990, 47 women were awarded the CSC in Sta. Catalina under the FAO-UNDP-ISFP, and most recipients were KBFAI members.

Livelihood and income sources

More than half of the respondents (27 farmers) planted coconuts as a major component of their agroforestry farms. Copra making ranks high because of a ready market and ease in generating copra. This livelihood activity does not require sophisticated skills, and when the price of copra goes up, the copra farmer earns well. The widespred growth of coconut in the area is due to the wide adaptability of the crop, available folk knowledge on coconut production and farm maintenance, and the steady supply of income every 45 days once the coconut is mature for harvest. Accessibility of the copra market is another reason. Copra buying stations are found within a 5 km radius of Sta. Catalina. Copra buyers in Atimonan and the adjacent towns of Pagbilao and Lucena City can readily pick up copra if the farmer cannot deliver it to the station.

Fourteen farmers raised forest and fruit tree seedlings in family nurseries as part of the KBFAI-CBFM program. This enterprise's high number of respondents indicates that the PO has a thriving business selling timber tree seedlings to different clients. KBFAI's good standing as a CBFM partner of the DENR made the latter patronize the seedlings needed for reforestation and disseminate to other organizations about KBFAI's collection. Some farmers were also engaged in off-farm work to augment income. These included operating a sundry or "sari-sari" store and engaging in construction work, particularly for young male members. Some senior citizens derived additional income from monthly pensions and financial support from relatives.

For many KBFAI members, more than on-farm income was needed to meet the needs and aspirations of family members. They augmented their income with off-farm work, especially when the agricultural work demand was low. Off-farm work provided immediate cash regularly. More regular income was derived from store operations, remittances, paid work in the barangay, transport service, and contractual work in construction. Household members helped generate additional income through off-farm work, whether their contribution was high or low. For instance, they helped produce handicrafts (rattan baskets, tiger-grass brooms, and bracelets from discarded tree parts), which the KBFAI initiated and put on sale. These crafts were not generating substantial income as they needed to be better promoted outside the barangay, and that product display within the RTC was intermittent.

Typology and characteristics of agroforestry technologies adopted

Nair (1993) classified agroforestry based on the type of components: agrisilviculture (trees + crops), silvopastoral (trees + animals/pasture), agrosilvopastoral (trees + crops + pasture/animal), and others (*i.e.*, multipurpose tree lots, apiculture with trees, and aquaculture with trees). In the study site, farmers practiced variations in agroforestry technologies adopted as they acquired experience and understanding of their circumstances and their relation to what farming practices are suitable.

Out of 50 respondents, 46 adopted the agrisilviculture agroforestry system using multistorey mixed cropping (**Table 1**). Under this system, more than half of the respondents (27) adopted a coconut-based multistorey mixed-cropping type. According to ICRAF (2021), a multistorey agroforestry system has at least three "storey" or "layers" of intercropped plants of different heights. The multistorey agroforestry cropping design of respondent adopters was also composed of different layers depending on the height of the crops. The upper layer included the large trees that produce timber for construction or furniture; the middle layer comprised the smaller trees (*e.g.*, many fruit trees and coconut palms), followed by bananas and coffee. There were cassava and herbaceous crops for the lower layers, like leafy green vegetables (*e.g.*, pechay and mustard).

Mixed cropping (2-3 crops) was commonly observed in the coconut-based multistorey agroforestry system. The understorey crops (mostly fruit trees) were randomly planted in spaces not covered by upper-layer plants, utilizing the sunlight penetrating the ground. Unlike intercropping or alley cropping, mixed cropping follows no definite pattern of crop configuration except for the plants in the upper canopy layer (for optimal growth and yield, coconut spacing is maintained at 7 m x 7 m at the very least). Many farmers find this most convenient in areas with steep slopes. Some farmers divided their land into parcels: some were intended for mixed cropping using fruit trees as understorey crops, while others were devoted to annual cash crops for optimal growth, easier maintenance, and management.

Other agroforestry farming systems were also observed. Four members practiced the agrosilvopastoral system. Aside from trees, the farmers tended livestock, did apiculture (raised bees for honey), or grew ornamentals, including the high-valued anahaw (*Livistona rotundifolia*) palm, as part of their agroforestry practice, with timber trees at the upper canopy layer serving as the animals' shelter against heat. Livestock included bees, chickens, and pigs, although some pigs became threats to young timber or fruit tree plantations, especially those that were not fenced. Economic benefits were visibly derived from apiculture and poultry. Harvested honey was marketed, as well as chicken meat. In addition, chicken dung was utilized as fertilizer in the agroforestry system. Livestock needed high maintenance in matters of feed and sanitation. Thus, the contribution of livestock to farmers' overall income could have been higher. Furthermore, seven members planted trees in farm boundaries to serve as windbreaks.

Table 1. Typology of agroforestry technology and their variants (crop/tree and animal components) adopted by the respondents.

Type of agroforestry based on component and system	Agroforestry component		
	Woody/Perennial/Palm	Annual	Animal
Agrisilvicultural	1. Anahaw, rambutan, langka, chico, santol	Pechay, mustasa	
(Multistorey)	2. Avocado, lanzones, mangga, cacao, gmelina, ipil-ipil, lanete, makaasim		
	3. Avocado, lanzones, mangga, cacao, mahogany, gmelina, ipil-ipil, lanete, makaasim	Banana, pineapple, taro, cassava	
	4. Avocado, lanzones, mangga, cacao, mahogany	Banana, pineapple	
	5. Avocado, rambutan, langka	Banana, pineapple, gabi	
	6. Avocado, rambutan, langka	Banana, pineapple, taro	
	7. Avocado, rambutan, langka, mahogany, narra	Banana, pineapple, gabi	
	8. Avocado, rambutan, mangga, mahogany, batino, narra, kalantas	Pineapple, taro, sili	
	9. Avocado, rambutan, mangga, mahogany, batino, narra, kalantas	Pineapple, taro	
	10. Avocado, rambutan, mangga, mahogany, batino, narra, kalantas	Pineapple, taro	
	11. Avocado, rambutan, mangga, mahogany, batino, narra, kalantas	Pineapple, taro, sili	
	12. Batino, narra, kalantas, bagtikan, guayabano, durian, dalungyan	Taro, cassava	
	13. Coconut	Banana, pineapple, taro, cassava	
	14. Coconut	Banana, taro, cassava	
	15. Coconut, avocado, lanzones, mango, cacao	Banana	
	16. Coconut, avocado, lanzones, mangga, cacao, mahogany	Banana, pineapple, taro	
	17. Coconut, avocado, lanzones, mangga, cacao, mahogany	Banana, pineapple, taro, cassava	
	18. Coconut, avocado, lanzones, mangga, cacao, white lauan, red lauan, mabolo, molave	Banana, pineapple, taro	
	19. Coconut, cassava, calamansi, mahogany, batino, narra, kalantas	Pechay, ginger	
	20. Coconut, gmelina, ipil, lanete, makaasim	Banana, taro, cassava	

Table 1. (Con't)

Type of agroforestry based on component and system	Agroforestry component		
	Woody/Perennial/Palm	Annual	Animal
	21. Coconut, gmelina, ipil-ipil, lanete, makaasim	Banana, pineapple, taro, cassava	
	22. Coconut, gmelina, ipil-ipil, lanete, makaasim	Banana, pineapple, taro	
	23. Coconut, gmelina, ipil-ipil, lanete, makaasim	Banana	
	24. Coconut, mahogany	Banana, pineapple, taro, cassava	
	25. Coconut, mahogany, batino, narra, kalantas	Banana, pineapple, taro	
	26. Coconut, mahogany, batino, narra, kalantas	Banana, pineapple, taro, cassava	
	27. Coconut, mahogany, gmelina, ipil-ipil, lanete, makaasim	Banana, pineapple, taro, cassava	
	28. Coconut, mahogany, batino, narra, kalantas	Papaya, taro, cassava	
	29. Coconut, mahogany, batino, narra, kalantas	Banana, cassava	
	30. Coconut, rambutan, langka	Banana, taro, cassava	
	31. Coconut, rambutan, langka	Banana, taro, cassava	
	32. Coconut, rambutan, langka	Banana, pineapple, taro, cassava	
	33. Coconut, white lauan, red lauan, mabolo, molave	Banana	
	34. Coconut, white lauan, red lauan, mabolo, molave, calamansi	Pineapple, banana	
	35. Mahogany, batino, narra, kalantas	Banana	
	36. Mahogany, mahogany, batino, narra, kalantas	Banana, cassava	
	37. Mahogany, narra, gmelina, ipil-ipil, lanete, makaasim, calamansi	Banana, taro	
	38. Mahogany, narra, gmelina, ipil-ipil, lanete, makaasim, calamansi	Banana, taro	
	39. Malunggay, guayabano, gmelina, ipil, lanete, makaasim	Cassava, taro, ginger, sili, tomato	
	40. White lauan, red lauan, mabolo, molave	Banana, sili, taro	
	41. White lauan, red lauan, mabolo, molave	Banana, sili, taro	
	42. White lauan, red lauan, mabolo, molave	Banana, sili, taro	
	43. White lauan, red lauan, mabolo, molave	Banana, sili, taro	
	44. White lauan, red lauan, mabolo, molave	Banana, sili, taro	
Agrisilvicultural	1. Coconut, anahaw, mahogany, coffee, mangachapoi, bagtikan	Pineapple	
(Multistorey and alley cropping			
Agrosilvopastoral	1. Coconut, anahaw, mahogany, coffee, mangachapoi, bagtikan	Pineapple	Bee, pig, chicken/ turkey
(Multistorey)	2. Coconut, avocado, lanzones, mangga cacao, mahogany, gmelina, ipil-ipil, lanete, makaasim	Banana, pineapple, taro, cassava	Pig
	3. Coconut, calamansi, white lauan, red lauan, mabolo, molave	Banana, pineapple, ginger, taro	Chicken, pig
	4. Coconut, malunggay	Banana, pineapple, taro, cassava	Bee

One farmer member adopted an alley cropping system type of agroforestry. The alley cropping system was regularly promoted during the KBFAI training on agroforestry, as this was widely adopted in upland farms in Mindanao in the 1980s. When the ISFP was launched in 1982, the Community Forestry Program (CFP) in 1989, and the implementation of the Center for People's Empowerment in the Uplands in 1992 (a highly selective program based on the potential and desirable characteristics of the PO), the prospective recipient-partner of the Stewardship Agreement had to undergo training in agroforestry, land management, enterprise development, and forest conservation. Given the slopes' steepness of many upland farms in Sta. Catalina, alley cropping was promoted to secure the farms' long-term productivity and protect soil, water, and biodiversity.

One respondent continuously practiced alley cropping, integrating pineapple and other cash crops in the narrow alleys developed through contoured hedges of leguminous shrubs. This system is one of the most labor-intensive agroforestry designs, especially in establishing contours and the consequent alleys. The steeper slopes can accommodate narrow alleys, while the lower areas can have wider alleys. All except one farmer discontinued the alley cropping practice due to aging and high maintenance of the alleys. To be successful in alley cropping, there is a need to rearrange the timberland to allow sunlight penetration, slow down the erosion of topsoil through the establishment of choice hedges, and constant intervention to maximize the complementation of the nutrient-rich hedges to the cash crops in the alleys. Given the labor demand and attention needed, alley cropping appears to work well when farms are nearby, with young farmers, or with those households having many adult males.

With the advancing age of KBFAI farmers, many favor the coconut-based mixed cropping agrisilviculture. Coconut is highly preferred as it grows easily and with low maintenance requirements while allowing farmers to grow other crops in between. Through the years of embracing different DENR-initiated programs, KBFAI members learned to integrate fruit trees into their coconut farms and to secure cash income. While waiting for the season of harvest and wages, they also planted short-term annuals – vegetables and root crops of different kinds and ornamentals. The respondents prefer a coconut-based multistorey mixed-cropping agroforestry system since they want a stable monthly income from coconuts. Coconut growing fits well with the aging population who have less energy for intensive farming while allowing them modest income every 45 days, the interval of coconut harvest. Once established, coconut requires less maintenance, and wide spacing allows fruit trees to grow without close management. Many respondents owned *coprahan* facilities for processing. Besides selling coconut in whole, they also processed the coconut meat into copra for sale to Quezon traders.

The coconut-based multistorey cropping system is one of the highly successful systems since this accommodates crops of different heights, canopy patterns, and root systems to maximize the use of sunlight, water, and nutrients (Sharma *et al.*, 2020). This promotes efficient cycling, ecological balance, and, subsequently, sustainable land use and maintains an ecological balance. In multistorey cropping, the existing planted trees are managed as an overstorey with an understorey of the woody or non-woody plants grown for various products. It allows simultaneously growing diverse plants of different heights in the same field (USDA, 2008). A multistorey cropping system is a very effective technique to counter degrading land use under farming, promoting sustainable productivity and profitability (Dutta & Gogoi, 2020).

KBFAI members knew they could not cut naturally growing timber trees in their farmlands because they are in timberlands. As DENR partners, they planted timber tree species on farm boundaries and steeper slopes as shelterbelts or windbreaks in compliance with their stewardship contract's 20% timber tree retention requirement. The less steep areas were planted with coconut, fruit trees, and short-term agronomic crops.

Table 2 shows the species planted by the respondents on their farms. The timber trees mostly planted by farmers were Mahogany and Falcata, both are fast-growing species. These trees were promoted during the CFP launched by the DENR in the early 1990s. Avocado, dalanghita or native orange, pineapple, and banana were the common fruits integrated into the coconut-based agroforestry system. Only a few farmers incorporated livestock, poultry, piggery, and apiculture in their upland farms. Farmers who could incorporate livestock in their agroforestry system have farms on less steep slopes than the majority that had a different favorable condition.

Forest trees were spaced at 2 m x 2 m or 3 m x 3 m apart for optimal growth. Tree strips also serve as windbreaks to protect the smaller crops from being easily damaged by strong winds and rainfall commonly occurring in the study site. The same system is applied to fruit plantations commonly intercropped with coconut palms. In areas with agronomic crops, the coconut palms were widely spaced, at 7 m x 7 m, to allow enough sunlight to

Table 2. Typology of agroforestry technology and their variants (crop/tree and animal components) adopted by the respondents.

Local name	Scientific name	Local name	Scientific name	Local name	Scientific name
Timber tree		Fruit tree/palm		Crop species and others	
Mahogany	*Swietenia macrophylla* King	Avocado	*Persea gratissima* Gaertn.	Banana	*Musa sapientum* L.
Batino	*Alstonia macrophylla* Wall. ex DC.	Lanzones	*Lansium domesticum* Correa	Pineapple	*Ananas comosus* (L.) Merr.
Narra	*Pterocarpus indicus Willd. forma indicus*	Mangga	*Mangifera indica* L.	Gabi	*Colocaisa esculenta* (L.) Schott
Kalantas	*Toona calantas Merr. & Rolfe*	Cacao	*Theobroma cacao* L.	Balinghoy	*Manihott esculenta* (Crantz)
Bagtikan	*Parashorea malaanonan* (Blanco) Merr	Dalanghita	*Citrus reticulata* Blanco	Malunggay	*Moringa oleifera* Lamk
White Lauan	*Shorea contorta* Vidal	Rambutan	*Nephelium lappaceum* L.	Ginger	*Zingiber officinale* Rosc.
Red Lauan	*Shorea negrosensis* Foxw.	Langka	*Artocarpus heterophyllus* Lam.	Sili	*Capsicum fructescens* L.
Kamagong	*Diospyros discolor* Willd.	Chico	*Manilkara sapota* (L.) Royer.	Tomato	*Solanum lycopersicum* L.
Molave	*Vitex parviflora* Juss.	Durian	*Durio zibethinus* Murr.	Tiger grass	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda
Gmelina	*Gmelina arborea* Roxb.	Dalungyan	*Artocarpus altilis* (Park.) Fosb.	Ube	*Dioscorea alata* L.
Ipil	*Instia bijuga* (Colebr.) O. Ktze.	Mangosteen	*Garcinia mangostana* L.	Palay	*Oryza sativa* Linn.
Lanete	*Wrightia pubescens* R. Br. subsp. *laniti* (Blanco) Ngan	Coffee	*Coffea arabica* L.	Pechay	*Brassica rapa subsp. chinensis* (L.) Hanelt
Makaasim	*Syzygium nitidum* Benth.	Guayabano	*Annona muricata* L.	Mustasa	*Brassica juncea* (L.)
Narig	*Vatica mangachapoi Blanco*	Santol	*Sandoricum koetjape* (Burm. f.) Merr.	Apiculture	
Gakakan	*Drypetes falcata* (Merr.) Pax & K. Hoffm	Coconut	*Cocos nucifera* L.	Poultry	
Palosapis	*Anisoptera thurifera* (Blanco) Blume	Anahaw	*Livistona rotundifolia* (Lam.) Mart.	Piggery	

herbaceous crops underneath while allowing the coconuts to spread well under their canopy. This configuration supports complementary relations and efficient space utilization.

Perceived benefits from the adoption of agroforestry

Respondents' decisions to adopt an agroforestry system depend on their perceived environmental, economic, and social benefits. The study by Jha *et al.* (2021) indicated that adopting agroforestry improves the adaptive capacity of farmers, the resilience of local farming systems, and the provision of diversified livelihood benefits. Likewise, Gebru *et al.* (2019) emphasized that agroforestry improves socioeconomic conditions and environmental health. Improving farmers' resilience is an outcome of improved livelihood that agroforestry affords. This leads to better access to fuelwood, fodder, timber, non-timber forest products, employment, and income opportunities.

Environmental benefit

Agroforestry benefits farmers and the environment (Mwase *et al.*, 2015) as this can improve agronomic productivity, enhance carbon sequestration, nutrient cycling, soil biodiversity, water retention, pollination, and reduce soil erosion (Sollen-Norrlin *et al.*, 2020). During the FGD, participants relayed that adopting agroforestry reduced soil erosion in their farms because planted trees protected the soil from the battering impact of heavy rains. In addition, the trees also protected the vegetable crops and livestock during strong winds and heavy rainfall. This was also the case with the coconut-based mixed cropping systems, the fruit tree mixed cropping with timber trees, and the agrosilvopastoral systems adopted by the KBFAI farmers. Planting different crops made the development of root matrices possible, allowing for the absorption and adsorption of nutrients and water storage. The primary roots of timber and fruit trees improved water absorption, while the lateral roots developed by coconut, trees, and annuals obstructed surface water flow and erosion of topsoil. The canopy layers slowed down the flow of rainwater through interception and prevented heavy splashing on the surface, thus, reducing soil erosion. According to Sharma *et al.* (2020), soil erosion is minimized if farmers grow more than one crop in the same field. In addition, it helps store water for the survival of other crops and lessens the risk of pests and diseases brought by diversification. Gebru *et al.* (2019) also claimed that agroforestry minimized soil erosion, helped decrease the incidence of natural hazards and floods, and ameliorated the microclimate.

Moreover, FGD participants shared that there was a significant change in farm productivity since they shifted to the mixed cropping system. Soil texture changed because of the presence of high biomass contributing to soil fertility and, at the same time, the filtering effect of the roots and debris on the floor, slowing down the surface flow along the slopes. Diversification of plants or crops and the proper selection and spacing of plant mixtures resulted in sustainable farming.

Economic benefit

Farming is the main source of income in the upland areas. Through the adoption of agroforestry, KBFAI farmers have generated substantial income without resorting to the previously practiced *kaingin* system. Makundente *et al.* (2020) highlighted the importance of relevant government agencies in encouraging farmers to practice agroforestry to benefit from crop yields and additional income from the sale of tree products. The economic benefits of agroforestry technology adoption validate the suitability of agroforestry as an upland production strategy. Its continued practice further proves the income position of KBFAI farmers.

The majority of KBFAI farmers adopted the coconut-based multistorey agroforestry system. Before agroforestry adoption, the members relied on selling fresh coconut harvest or extracted coconut oil, which was sold at a low price. With agroforestry, KBFAI members were no longer dependent on coconut income alone. They derived income from harvested fruit trees or agronomic crops planted along with coconut and timber trees and sales of tree seedlings. The short-term crops, seasonal fruit harvests, and seedling sales provided economic relief and freedom from being cashless for a long time.

Active members of KBFAI maintained the PO-owned nursery by weeding or removing unwanted sprouts regularly to maintain the seedling quality. In 2019, as part of the CBFM program, the KBFAI members sold guayabano seedlings in the community from their nurseries. Raising seedlings for sale was still in its infancy. Members are in the trial-and-error stage of the germination process, learning more about soil suitability, preparation, and pest and insect attack prevention.

People in upland areas engaged in different ways to earn. The agroforestry system provided food and non-food forest products. Aside from selling fruits and working in *coprahan*, basket and bag weaving, tiger broom making, and bracelet making (out of rolled paper) were also practiced by the members. These crafts were made mostly by female members during their free time while having casual conversations with other KBFAI members.

The products served as a source of additional income. Attractive designs for baskets, bags, and bracelets made them saleable at a reasonable price. These products were displayed in the RTC and the public market. Residents of Atimonan have been encouraged by their local government to patronize hometown-made products. Sales started to pick up but dipped low during the pandemic period.

The monthly income (**Table 3**) indicates the average income derived by the respondents from theiron-farm and off-farm livelihood. On average, farmers earned PHP 1,800 from selling *copra*. This amount needs to be improved to meet the basic needs of farmers in 2018. Income was augmented through other livelihood options adopted as part of the agroforestry system design. One member shared that in 2018, his family earned around PHP 100,000 from tending 13 heads of pigs. From this revenue, that member was able to build a house with two rooms for his family. Other agroforestry farm produce helped meet the farm-household daily needs (*i.e.*, fuelwood and fruits).

Some financially challenged members, particularly middle-aged farmers, sought alternative income sources. They took off-farm work in either construction, transport service, or operating a small neighborhood sundry store (sari-sari store) that may fetch around PHP 6000-8000 mo-1 extra income. Other additional income may be derived from the KBFAI-initiated livelihood for its members, such as basket weaving, bracelet making, and nursery maintenance.

Social benefit

For most KBFAI members, as relayed during FGD and interviews, the training on agroforestry helped them revisit their traditional way of farming prior to the modernization of agriculture in the 1960s and 1970s, which made farmers shift to monocropping, use of early maturing, high-yielding plant variety, and application of chemical and fertilizer inputs to obtain a high yield from planted rice, and short-term crops. The expected high yield was short-lived, and less than a decade after adoption; the farmer was saddled with debts due to increasing production requirements and the rising cost of fertilizer and pesticides. Due to modernization, many were forced to sell their farms in the lowland and move to timberlands. Recognizing that the government owned these lands and banned tree cutting without a permit, the informal settlers had to implement a quick way of earning money – through the adoption of the *kaingin* system and charcoal making (during timberland clearing, the trees or branches cut were made into charcoal for sale). Kaingin making was the easiest way to acquire additional farm parcels in forestlands. The clearing allowed them to raise short-term crops and make available cash income at the expense of the environment. With declining soil fertility and farm productivity through continued land use, the KBFAI farmers realized the unsustainability of the practice. This pushed them towards deeper poverty condition.

The formal training on agroforestry revitalized upland farming in Barangay. Sta. Catalina. The training helped them re-imagine the techniques of their ancestors and the attendant cultural values and beliefs. Re-integration of trees and other farm components was compatible with their early beliefs on land use; hence, the formal training

Table 3. Estimated average monthly on-farm & off-farm income of the KBFAI member respondents.

Type of livelihood sources	Specific livelihood income sources	Frequency	%	Estimated average monthly income by respondents (PHP)	Remarks
On-farm sources					
	Coprahan	27	54	1,800.00	
	Piggery (13 heads farmer-1)	3	6	833.00*	Experience from a single farmer
	Charcoal making	2	4	600	
	Selling crops	5	10	400	
	Poultry	1	2	2000	
	KBFAI: Nursery maintenance	14	28	400	
Off-farm sources					
	Construction work	2	4	800	
	Truck and tricycle driving service	2		5,000.00	
	Sari-sari store operation	7	14	6,000.00	
	Pension/ support from relatives	7	14	6,000.00	
	Barangay. wage work	2	4	2,600.00	
Under KBFAI					
	Bracelet making	5	10	100	
	Basket weaving	4	8	1,000.00	

easily found its application in many KBFAI members' farms

Oduniyi & Tekana (2019) concluded that membership in the farmers' association is a significant variable in adopting agroforestry practices. The KBFAI became a channel of new knowledge about agroforestry, increasing the PO's trustworthiness to its members. Members who saw and experienced the able and sincere leadership of KBFAI made them confident to adopt agroforestry technologies and maintain their membership in the organization.

KBFAI members' training from the various government and non-government agencies helped them improve their social and technical skills. Aside from agroforestry training conducted by the DENR from 2010-2012, members participated in the Forest Products Research and Development Institute (FPRDI) training through its project funded by the International Tropical Timber Organization (ITTO). This training included organizational development and management, basic handicraft skills, craftsmanship development (advanced handicraft skills), product development training, product costing, product trading and documentation process, product quality and quality management, product storekeeping, and booth fair management (FPRDI-ITTO, 2012). During these two years, the members were given a package to develop and market forest-based products and the PO capacity to handle business. On the other hand, the members' social capital developed through friendships, camaraderie, connections, and linkages with government agencies to voice their concerns without fear during public fora and conferences, to which the PO leaders were consistently invited. Individual members were also encouraged to share their experience and knowledge about agroforestry farming, particularly on planting and maintenance. Jara-Rojas *et al.* (2020) claimed that social capital and networking could be crucial in spreading agroforestry as a sustainable land use practice. Oduniyi & Tekana (2019) suggested strengthening farmers. The presence of farmer associations, particularly in rural areas, significantly contributes to the diffusion of agroforestry technologies.

The agroforestry system adopted by the KBFAI members was beneficial due to the multiple products it provided. Although agroforestry was earlier practiced, knowledge and skills were not widely disseminated nor homogenized, and the benefits mainly accrued to individual farmers only. The social capital that allowed for greater interaction and connectivity did not improve because not all members actively participated in PO-led activities. This also did not deter upland residents from continuing its *kaingin* and charcoal making that destroyed many upland zones, especially in Barangay. Sta. Catalina, the fragile uplands and watershed connecting to Lamon Bay, bordering many Atimonan and Quezon coastal communities.

Past experiences were given due consideration in the current agroforestry technology diffusion process, which emphasized collective development, the conservation of the upland environment, the maturing of the KBFAI so that it can continue to deliver the services needed by the members, and the continued development of members' knowledge on organization and management, technical skills, and life skills. The benefits of the latter agroforestry training accrued to individual members and the KBFAI organization.

Disabling and enabling factors in the adoption of agroforestry

Sollen-Norrlin *et al.* (2020) raised several challenges in adopting agroforestry technologies. High costs of implementation, lack of financial incentives, limited agroforestry product marketing, and lack of education, awareness, and field demonstrations are some lingering concerns in agroforestry technology adoption.

In the case of KBFAI, most members belonged to the senior citizen category; thus, the farmers' time to manage and maintain their agroforestry system needed to be improved. In many agroforestry farms, there was overshading due to the DENR-funded National Greening Project (NGP) that the PO implemented. The project required participating KBFAI members to plant indigenous timber tree species in the area covered by the CBFM Agreement, where the farmers already maintained their agroforestry practice. After the DENR monitoring and payment, the senior KBFAI members were forced to cut the younger indigenous trees to remove competition posed by these trees to the fruit trees and cash crops established as components of their agroforestry practice.

Another challenge or disabling factor pertains to the DENR's changing policy regarding timber trees planted by KBFAI members in keeping with the 20% tree retention requirement of their stewardship contract since 1984. Those who planted timber species earlier in response to the ISFP in the early 1980s and the CFP in the 1990s wished to cut the mature trees ready for harvest. However, DENR implemented the logging ban (supposedly applicable only to natural stands) as stated in Executive Order 23, series of 2011. As relayed by the participants, the DENR suspended the tree harvesting permit. It dampened the spirit of KBFAI members and made them suspect the DENR's programs overall. Harvested timber of high-value tree crops planted by KBFAI members could transform their economic condition due to the country's high demand for construction and furniture wood. Climate change impacts such as typhoons also challenged their agroforestry farming system and livelihood sources. The vulnerability of the agroforestry farms diminished but not substantially reduced.

Finally, quarrying in the upper part of Sta. Catalina affected the farms of agroforestry practitioners as big stones cascaded into their farms and disturbed wild animals, particularly the wild pigs. The pigs now frequented their farms and devoured crops.

Enabling factors in agroforestry technology adoption

Participants in the FGD mentioned that agroforestry technology adoption made farmers more innovative and drawn to voluntary engagement to contribute to environmental restoration. Many respondents in the past were involved in *kaingin* and charcoal making, two livelihood practices that degraded their environment. Although the KBFAI prohibited *kaingin*-making, a few continued this practice due to perceived benefits and socio-economic reasons. After attending training and seminars, negative behaviors had been reduced substantially, with only a few KBFAI members continuing the environment-destructive practices (purportedly to improve the quality of acidic soil from the ashes produced in forest debris burning).

The rocky areas on the upper slopes of Sta. Catalina also prevented some farmers from improving their agroforestry farms due to limited space to grow agricultural and forest crops. Some members did not manage their areas before because they believed they could not plant their preferred crops according to their desired arrangement due to rocky surfaces. Some farmers, however, did not see the rocks as a deterrent. They became innovative and utilized the rocks for fencing purposes. Rocks stood out aesthetically and protected the crops threatened by livestock or wild animals.

The lack of concrete plans about tree harvesting permits for planted trees created confusion as to whether the farmer could harvest the timber species planted in past programs as promised. Although the approved Community Resource Management Framework (the operational plan facilitated by the DENR-CENRO) was formulated by the KBFAI, members have yet to enjoy income from harvested trees. This is the primary reason some farmers were discouraged from sustaining agroforestry practices, alongside the delayed returns to investment because tree farming has a 20- to 30-year gestation period for slow-growing species. The only thing that KBFAI members thoroughly enjoy is the tenure that guarantees access and control over the timberland covered by their stewardship contract or CBFMA.

Despite the challenges, KBFAI members continued to practice agroforestry because the benefits far outweighed the costs and burdens. As shown in **Table 4**, there are enabling factors in adopting the agroforestry system. KBFAI membership enabled upland farmers to value the ecological services of the surrounding timberland, contribute meaningfully to protecting the environment, and help individual members through training

Table 4. Identified enabling and disabling factors in the adoption of agroforestry during FGD.

	Enabling factor	Disabling factor
Social	Build connections/linkages with the government and non-government agencies	Lack of concrete plans for tree resource harvesting/utilization
	Devoted leaders; trustworthy leadership	Aging farmers
	Training and seminars improved competencies	
Environment	KBFAI has good and well-equipped facilities	Water supply problems and some rocky road areas
	Have a strong CBFM	
	Provision of land stewardship (CSC)	
Economic	AF products provide continued income	Need for more marketing outlets for AF products and handicrafts
	KBFAI projects helped members to generate more income	

to build their competencies, enhance soil productivity, and provide the means to improve their way of life and social status. Once permitted, economic rewards from timber harvesting would tilt the balance in favor of sustained agroforestry practice.

CONCLUSION

Adopting agroforestry technologies provided the KBFAI members with multiple benefits from the multiple products and services that the technology provides, encompassing environmental, economic, and social benefits. Most (46 out of 50) of the KBFAI member respondents adopted the agrisilviculture (trees + crops) type of agroforestry system in Barangay Sta. Catalina, Atimonan, Quezon. Under this system, more than half of the KBFAI members adopted a coconut-based multistorey mixed cropping agroforestry system that entails less maintenance, especially for aging KBFAI members. The agroforestry system is the primary income source for all KBFAI members. It helps members in creating livelihood programs through food or non-food products. Non-food product livelihood includes bag and basket weaving, broom and bracelet making, while food products produce fresh and dried fruits and chips.

Membership in KBFAI serves as a vehicle for social capital and human capital development. Individual members became technically and psychologically skilled, while the KBFAI increased in quality leadership and improved its networks and physical assets. Empowered leaders led the association to seek support from government agencies to strengthen environmental protection and rehabilitation in the area. Soil erosion and *kaingin* making were no longer widely observed in the area with the adoption of agroforestry technologies by almost all members. Trees on farms protected crops from strong winds and heavy rains.

Sustainability issues on agroforestry are still raised since the younger generation was not interested in farming. Most KBFAI members reached 60 to 80 years old, an age range of less agility. Senior members needed to be more successful in encouraging their young to engage in agroforestry farming. Despite their awareness of agroforestry benefits, the youth mostly preferred to work in white-collar jobs. The restrictions on timber harvesting also dissuaded many KBFAI members from tree-growing or adopting tree-based multi-cropping system. Respondents practiced multistorey mixed cropping because it was hard to apply preferred agroforestry designs in spaces planted to timber as required by their new project with the DENR (NGP site) and filled with rocks. They adopted a multistorey agroforestry system with coconuts, bananas, and other crops requiring less maintenance and with an established market.

This study provided insights into the different species combinations of the woody perennials and non-perennial agroforestry components. Sources of off-farm income that augment farmers' household income are also revealed in this study, along with the social, economic, and environmental enabling and disabling factors in adopting the agroforestry system.

LITERATURE CITED

DENR-CENRO [Department of Environment and Natural Resources–Community Environment and Natural Resources Office-Calauag]. (2019). Compliance monitoring report of CBFM implementation and management of Kapit-Bisig Farmers Association, Inc. (KBFAI).

DENR-CENRO [Department of Environment and Natural Resources–Community Environment and Natural Resources Office-Calauag]. (2020). Compliance monitoring report of CBFM implementation and management of Kapit-Bisig Farmers Association, Inc. (KBFAI).

Duthy, S. & Bolo-Duthy, B. (2003). Empowering people's organizations in community-based forest management in the Philippines: The community organizing role of NGOs. *Annals of Tropical Research*, *25*(2), 13–27.

Dutta, S. & Gogoi P. (2020). Multistorey croppingsSystem: A profitable approach for sustainable Productivity. Agriculture and

Food. E-Newsletter. ISSN 2581-8317. <https://www.researchgate.net/publication/344014299_Multistorey_Cropping_System_A_Profitable_Approach_for_Sustainable_Productivity>.

Gebru, B. M. Sonam, W. W., Sea, J. K., & Lee, W. K. (2019). Socio-ecological niche and factors affecting agroforestry practice adoption in different agroecologies of Southern Tigray, Ethiopia. *Sustainability*, *11*, 3729. https://doi.org/10.3390/su11133729.

ICRAF [World Agroforestry Center]. (2021). Multistorey agroforestry. *In:* Chapter 4: Agroforestry. <http://apps.worldagroforestry.org/Units/Library/Books/Book%2082/ imperata%20grassland/html/4.8_mutlistory.htm?n=27>.

Jara-Rojas, R., Soraya, R., Lisandro, R., Fleming-Muñoz, D., & Engler, A. (2020). Factors affecting the adoption of agroforestry practices: Insights from silvopastoral systems of Colombia Multidisciplinary Digital Publishing Institute. *Forests, 11*, 648; https://doi.org/10.3390/f11060648.

Jha, S., Kaechele, H., & Sieber, S. (2021). Factors influencing the adoption of agroforestry by smallholder farmer households in Tanzania: Case studies from Morogoro and Dodoma. *Land Use Policy*, *103*, 105308. https://doi.org/10.1016/j.landusepol.2021.105308. 10.1016/j.landusepol.2021.105308.

Torreta, N. K. N. (1992). The participation of women in upland development: The case of upland women in Sta. Catalina, Atimonan. <https://elibrary.pcaarrd.dost.gov.ph/slimsadmin/upload/2019-01-15-01_ab_55703.pdf>.

Mukundente, L., Ndunda, E., & Gathuru, G. (2020). Socio-economic and institutional factors affecting smallholder farmers to adopt agroforestry practices in the southern province of Rwanda. *International Journal of Agricultural Science and Food Technology*. ISSN: 2455-815.<https://www.peertechzpublications.com/articles/IJASFT-6-157.pdf>.

Meeteren, R. V. (2012). Can the rainforest of Puerto Princesa be preserved from unsustainable development: Forest conversion (*Kaingin*) and charcoal collection environmental impact assessment in North West Puerto Princesa, Palawan, Philippines. <http://finsandleaves.org/wp-content/uploads/2018/06/R._van_Meeteren_2012_Can_the_rainforests_of_Puerto_Princesa_be_preserved_from_unsustianable_development.pdf>.

Mwase, W. F., Sefasi, A., Njoloma, D. P. J., Betserai, I. N., Manduwa, D., & Nyaika, J. (2015). Factors affecting adoption of agroforestry and evergreen agriculture in Southern Africa. <https://www.worldagroforestry.org/publication/factors-affecting-adoption-agroforestry-and-evergreen-agriculture-southern-africa>.

Nair, P. K. R. (1993). An introduction to agroforestry. KLGWER Academic publishers in cooperation with international center for research in agroforestry. <https://apps.worldagroforestry.org/Units/Library/Books/PDFs/32_An_introduction_to_agroforestry.pdf?n=161>.

Sharma, A., Chaudhary, N., Sharma, R., & Anjanawe, S. (2020). Multi storied cropping system in horticulture - An approach for more crops per unit area of land. *Journal of Pharmacognosy and Phytochemistry*, SP6, 25–28.

Oduniyi, O. S. & Tekana, S. S. (2019). Adoption of agroforestry practices and climate change mitigation strategies in North West province of South Africa. *International Journal of Climate Change Strategies and Management, 63*, 1(1)–14(5).

PSA [Philippine Statistic Authority]. (2020). Census of population and housing population counts declared official by the president. <https://psa.gov.ph/content/2020-census-population-and-housing-2020-cph-population-counts-declared-official-president>.

Sollen-Norrlin, M., Ghaley, B. B., & Rintou, N. L. J. (2020). Agroforestry benefits and challenges for adoption in Europe and beyond. *Sustainability*, *12*, 7001. https://doi.org/10.3390/su12177001. <https://www.mdpi.com/2071-1050/12/17/7001/pdf>.

USDA [United States Department of Agriculture]. (2008). Multistory cropping. USDA natural resources conservation service-practice code 379. <https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026600.pdf>.

p-ISSN 2012-3612 │ e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 │ Number 1 │ pp. 18–32│ 2023

Dynamics and drivers of deforestation in the Philippines

Marie Jessica C. Gabriel[1*]

[1]*Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. Deforestation is one of the biggest environmental problems in the world. It is an old ecological problem, yet the deforestation rates and causes are still debated in many areas. In the Philippines, there are numerous but conflicting forest cover estimates. Also, there is no agreement on the causes of deforestation, and information on contemporary causes is limited. This research aims to shed light on the rate and causes of deforestation in the Philippines by conducting a literature review from 1980 to 2020. This study shows that estimating deforestation rates is difficult because of the differences in methodology, data used, and forest definition in quantifying the forest cover of the Philippines. Nevertheless, various sources indicated that forest cover decreased from 1980 to 2010 and increased from 2010 to 2020. Proximate causes of deforestation were primarily agricultural expansion, wood extraction, and built-up extension. Underlying causes were mainly demographic and poverty factors; market demand and economic development factors; and governance, policy, and institutional factors. The results also revealed that the different causes were linked to each other. Temporal analysis of the causes of deforestation showed that wood extraction was an important driver from 1980 to 2020. Infrastructure development had increasing significance from 1980 to 2020. Agricultural expansion remained an important driver of deforestation throughout the study period. The perpetuation of agricultural expansion and the rise of infrastructure development as drivers of deforestation calls for proper land use planning, land classification, and stronger protection of protected areas. It is also suggested to further investigate wood extraction as a driver of deforestation.

Keywords: forest area, forest loss, land cover change, temporal analysis

Article Information
Received 19 January 2023
Accepted 13 July 2023
Published online 16 October 2023
*Email: mcgabriel@up.edu.ph

INTRODUCTION

Deforestation remains one of the biggest global environmental problems (IUCN, 2017). According to Food and Agriculture Organization (FAO) (2012), deforestation is the "conversion of forest to other land use or the permanent reduction of tree canopy cover below the minimum 10 percent threshold." It includes forested areas converted to other land uses, such as agriculture, pasture, water reservoirs, and urban regions. The latest State of the World's forest resources report by FAO (2020) states that forests globally are slowly increasing. Still, deforestation remains huge at around 10 M ha of forests lost annually from 2015 to 2020.

Deforestation impacts biodiversity, ecosystem services, livelihoods, climate, and food security (FAO, 2020). The loss of forest cover is the leading cause of the 20,334 tree species being added to the International Union for the Conservation of Nature (IUCN) red list and putting more than 1,400 tree species into the list of critically endangered species needing immediate action (IUCN, 2017). It also affects around 1.6 B people whose livelihoods depend on forest resources (IUCN, 2017). Forests are also sources of ecosystem services, such as food and water, climate regulation, culture, and scenic and landscape for tourism (Lindberg *et al.*, 1997). Deforestation and forest degradation are also significant contributors to global greenhouse gas emissions of 5.8 $GtCO_2$ yr^{-1} (Nabuurs *et al.*, 2007). These pose a considerable concern not only globally but also at the national level.

The Philippines has suffered severe deforestation. Hughes (2017) mentioned that around 93% of the primary forests had been removed. The problem of deforestation in the country has caused a loss of biodiversity (Pang *et al.*, 2021), food and water insecurities, displacement of indigenous peoples (Walpole, 2011), and claimed thousands of lives due to flooding and landslides (Hance, 2011). The severe impact of deforestation in the Philippines has led the 2011 Philippine Government to implement a nationwide moratorium on logging (Executive Order No. 23, s. 2011) and the National Greening Program (NGP) (Executive Order No. 26, s. 2011). As a result, the Philippines was listed as one of the top ten countries with increased forest cover from 2010 to 2015 (FAO, 2016). However, deforestation is still in place, especially in areas not subject to NGP (Perez *et al.*, 2020). Thus, it is still relevant to talk about deforestation in the country.

Previous deforestation studies cited numerous drivers (Bee, 1987; Acosta, 1989; Kummer, 1992; Liu *et al.*, 1993; Carter, 1999; Hosonuma *et al.*, 2012; Carandang *et al.*, 2013; Hughes, 2017). Some studies cite a single cause of deforestation, such as logging (Wertz & Kongphan, 2008). Others name numerous direct or proximate drivers (*e.g.*, Bee, 1987; Kummer, 1992) and underlying drivers (*e.g.*, Acosta, 1989; World Bank, 1989). In reality, these different causes of deforestation work in a system linked to each other (Geist & Lambin, 2002; Carandang *et al.*, 2013). Thus, it is essential to look at deforestation from a broader perspective where different drivers are at play (FAO, 2020).

Further, these drivers vary across time (Kummer, 1992; Bankoff, 2007; Carandang *et al.*, 2013) and space (Hosonuma *et al.*, 2012). With the change in administration, political interests could also change from forest production to protection (Kummer, 1992). Thus, the state of deforestation also changes. Similarly, the situation and context vary in every place. For example, Latin America is into agri-business; therefore, agricultural expansion in cattle ranching and soya production is the primary driver (Hosonuma *et al.*, 2012). Whereas in Southeast Asia, they are known for their timber and palm oil. Thus, deforestation due to logging and tree plantations is rampant (Wertz & Kongphan, 2008; Hughes, 2017). Deforestation is a dynamic environmental problem. Hence, it is necessary to have an up-to-date understanding of its drivers to develop policies and strategies that fit the current situation (Hosonuma *et al.*, 2012). Further, a local identification of causes of deforestation is also essential to have a more informed decision in developing projects at the local level (FAO, 2020).

In the Philippines, information on the contemporary causes of deforestation remains limited (The Philippines REDD-plus Strategy Team, 2010). The latest synthesis on the drivers of deforestation by Carandang *et al.* (2013) used drivers listed in the Philippine REDD-plus strategy that were solicited from forest users and experts (The Philippines REDD-plus Strategy Team, 2010). Also, Carandang *et al.* (2013) focused only on four sites in the Philippines – Quezon, Southern Leyte, Palawan, and Misamis Occidental. With the recent implementation of new policies that promote forest conservation in the Philippines (*i.e.*, Executive Order No. 26, s. 2011; Executive Order No. 23, s. 2011), there have been changes in the state of deforestation in the country that were not covered by Carandang *et al.* (2013).

This study responds to the call for a more complex perspective of understanding the drivers of deforestation. It aims to compare forest cover estimates of the Philippines and identify the causes of deforestation from 1980 to 2020. The outcomes shall provide the latest information about deforestation in the Philippines, which is beneficial in policymaking and developing national REDD-plus strategies.

METHODOLOGY

Literature search and screening

This study conducted two literature searches. One literature search for forest cover estimates and another for the causes of deforestation. Sources published from 1980 to 2020 were obtained using the Scopus, Web of Science Core Collection, and Google Scholar platforms. In addition, Google Web Search was also used for forest cover sources to capture government reports (*i.e.*, DENR, FAO).

Keywords used for the sources of forest cover were forest cover, forest area, and the Philippines. While for the causes of deforestation papers, the keywords used include deforestation, forest loss, forest decline, land use/cover change, causes/ drivers of deforestation, and Philippines.

The search was done on 19 February 2021, for the causes of deforestation sources and on 23 March 2021, for the forest cover sources. In total, 734 papers on the causes of deforestation and 234 sources for the forest cover were exported to CADIMA. This free web-based tool supports systematic reviews, systematic maps, and literature reviews for subsequent screening.

A two-stage review in CADIMA was done to examine the articles' relevance to the study's objectives. First, the title and abstract were reviewed. Followed by full-text screening. The criteria used in each stage are presented in **Table 1**. After the full-text screening, the final number of papers used in this study was 130 for causes of deforestation and 33 for the forest cover estimates.

Data extraction and analysis

The forest cover estimates were extracted and compared from each source. The 2003, 2010, 2015, and 2020 land cover data of DENR were further analyzed by doing crosstabulations to determine the transitions of forested areas and where these changes are concentrated. General classes such as agriculture, open/barren, brush/ shrubs, grassland, forest, and built-up addressed the differences in the land cover classes used in each period. Annual and perennial crops were grouped into agriculture, and fallow areas were included in barren/open.

Meanwhile, the analysis of the causes of deforestation followed the framework of Geist & Lambin (2002), wherein the causes of deforestation may be classified into proximate and underlying causes. The broad and specific proximate and underlying causes of deforestation were extracted and counted. The papers were then classified into single, two-factor, three-factor, and four-factor causations.

The relationships of the different causes of deforestation were also noted to establish the various causal chain relationships. For simplicity, up to the second level of association was done in this study. The papers with the causal chain relationship were classified based on the following:

1. PROX – PROX – proximate causes driving other proximate cause/s (*e.g.*, logging companies constructed road networks inside the forest)
2. PROX – UNDER – proximate causes having feedback on underlying cause/s (*e.g.*, construction of roads enhancing market access)
3. UNDER – UNDER – underlying causes driving other underlying cause/s (*e.g.*, unemployment causing upland migration)
4. UNDER – PROX – underlying causes driving proximate cause/s (*e.g.*, upland migration causing shifting cultivation in the uplands)

To know how deforestation developed through time, the period when the causes of deforestation were reported was also noted. The causes of deforestation were classified into four periods – 1980-1989, 1990-1999, 2000-2009, and 2010-2020.

RESULTS

Forest cover estimates

Estimates of the forest cover of the Philippines varied from one source to another (**Figure 1**). Only the Philippine Forestry Statistics (PFS) of DENR and Forest Resources Assessment (FRA) of FAO had historical records of the Philippine forest cover.

The Forest Management Bureau (FMB), under the DENR, was responsible for publishing the PFS annually. The 1991 to 1997 forest cover was a projection from the 1988 Philippine-German Forest Inventory Project (P-GFIP). The P-GFIP was the second comprehensive forest inventory following the 1969 forest inventory conducted by the Philippine government (FMB, 1988). After the 1997 PFS, the next release of forest cover statistics was in 2003, 2010, 2015, and 2020. These were

Table 1. Criteria used in the two-stage screening process.

	Forest cover source	Cause of deforestation source
Title and abstract screening	a. The study covers the entire Philippines; and b. The focus of the study is on the forest ecosystem.	a. The study involves the Philippines or is conducted in the Philippines; and b. The focus is on the terrestrial forest ecosystem.
Full-text screening	a. The paper has a quantification o national forest cover; and b. The forest cover is from 1980 to 2020.	a. It talks about deforestation from 1980 to 2020; and b. It discusses the causes of deforestation.

based on forest inventories conducted by the National Mapping Resources and Information Authority (NAMRIA). From 1997 to 2010, the country's forest cover is decreasing, and it starts to increase from 2010 to 2020.

The FRA estimates were based on country reports. The FMB was responsible for preparing the Philippines' report to FAO, which was mainly coming from the PFS. Despite collecting country data from government agencies, variations were still observed in the PFS and FRA data. It was only in FRA 2020 that the DENR's and FAO's estimates were the same. It was also evident that the various editions of the FRA offered different historical estimates of forest cover.

Other estimates of forest cover were also collected from projects and published research. In 1988, two independent nationwide forest inventories were conducted – the 1988 Philippine-German Forest Inventory Project (P-GFIP) and a forest inventory commission by the World Bank and the Swedish Space Corporation (SSC). Comparing 1988 P-GFIP and SSC estimates, the SSC was higher by around 645,400 ha. The Environmental Science for Social Change (ESSC) also mapped the country's land cover in 2002 to compare it with the 2003 PFS. A difference of more than 1 M ha was found in the ESSC and PFS estimates of forest cover in 2002 and 2003, respectively. Meanwhile, a study by Estoque *et al.* (2018) estimated the 2010 forest areas from different remotely sensed images, namely CCI 300, Landsat, MODIS250, MODIS500, GTCANOPY30, ALOS 25, and GLOBELAND30. Despite having the same period, the various remote sensing products showed different estimates of forest cover.

Forest transitions

Deforested areas across three periods were generally decreasing (**Table 2**). The majority of the forest loss in 2003-2010 and 2010-2015 were located in Region 4B, Region 2, and CAR. Meanwhile, in 2010-2015 and 2015-2020, most deforested areas were in CAR, Region 4B, and Region 13. These were also the regions where most forested areas can be seen.

Deforested areas transitioned to brush/shrub has increased from 40% of deforested areas in 2003-2010 to 65% in 2010-2015 and 69% in 2015-2020. Forested areas converted to brush/shrub were mostly seen in CAR, Region 4B, and Region 13. Regarding agricultural expansion, 24% of deforested areas in 2003-2010 and 2010-2015 were converted to agricultural areas and 16% in 2015-2020. Most transitioned areas to agriculture were in Regions 2, 4B, 5, 8, 13, and CAR.

Forest conversions to built-up areas were relatively increasing from 0.46% of deforested areas in 2003-2010 to 0.92% in 2010-2015 and 1.60% in 2015-2020. Increasing conversion to built-up areas was observed in regions such as Regions 1, 3, 4B, 6, 9, 11, and 12.

Causes of deforestation

The majority of the papers cited two factors of deforestation (47%, N=130) followed by single-factor (35%), three-factor (16%), and four-factor (2%). Of which, the tandem of wood extraction and agricultural expansion stands out, with 45 papers (35%) mentioning their relevance (**Table 3**).

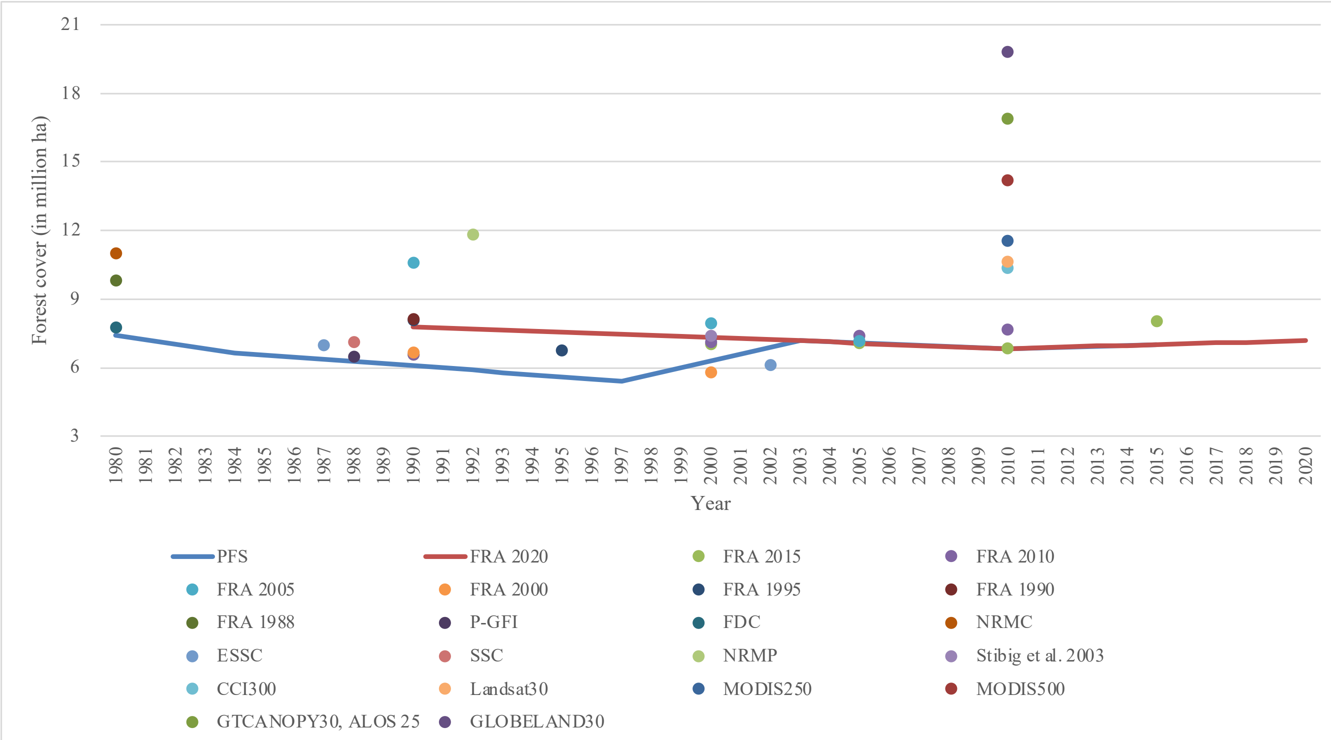


Figure 1. Study location showing Barangay Sta. Catalina.

Regarding specific proximate causes, most papers mentioned upland agriculture (52%, N=130), including agricultural cropping done by upland farmers, whether shifting or static cultivation (Table 4). Commercial logging (48%) and timber poaching (27%) dominated wood extraction. The difference between these examples of wood extraction was that the former was run by logging companies (Lasco *et al.*, 2001; Carandang *et al.*, 2013), while timber poaching was done by local individuals and displaced logging company workers and operating in a smaller scale than commercial logging (Hayama, 2000; Wallace, 2011).

These proximate causes were driven by underlying causes which were mostly single factors (38%, N=130), wherein more than half of the papers (53%, N=49) cited demographic and poverty factors (**Table 5**). This was followed by three-factor (21%, N=130), where most papers (74%, N=27) mention demographic and poverty factors, market demand and economic development, and governance, policy, and institutional factors. In terms of specific underlying factors, the majority of the papers mentioned (Table 6) the increase in population (40%), upland migration (28%), and poverty (18%).

The linkages between proximate and underlying causes revealed that an underlying cause may drive two to three proximate causes. This was observed in demographic and poverty factors driving agricultural expansion (45%, N=130), wood extraction (14%), and infrastructure extension (4%). Market demand and economic development also influenced agricultural expansion (14%), wood extraction (19%), and infrastructure extension (5%). The governance, policy, and institutional factors contributed to agricultural expansion (15%), wood extraction (25%), and infrastructure extension (5%).

Aside from underlying causes driving proximate causes, other interlinkages and feedback among the proximate and underlying causes were also observed. A feedback loop among underlying causes was seen. For instance, demographic and poverty factors also drove other factors (19%, N=130). This was observed in poverty,

Table 2. Forest transitions for the period of 2003-2010, 2010-2015, and 2015-2020.

Region	Period	Agriculture	Brush/ Shrubs	Built-up	Grassland	Open/ Barren
NCR	2003-2010		7	3		
	2010-2015					
	2015-2020	7	19	18	1	
CAR	2003-2010	20,518	54,749	825	65,439	508
	2010-2015	20,287	80,380	1,793	13,457	281
	2015-2020	4,908	39,316	975	5,686	476
1	2003-2010	4,833	34,437	190	52,387	48
	2010-2015	905	14,835	172	2,407	36
	2015-2020	577	6,898	222	1,045	14
2	2003-2010	35,114	56,218	901	113,411	770
	2010-2015	20,665	50,142	758	12,365	1,049
	2015-2020	7,161	20,022	435	4,579	661
3	2003-2010	12,612	50,738	679	72,064	706
	2010-2015	9,526	22,743	398	4,906	566
	2015-2020	2,051	19,901	426	5,212	893
4A	2003-2010	25,225	36,316	640	3,372	491
	2010-2015	19,723	15,379	323	349	75
	2015-2020	3,574	6,062	164	819	156
4B	2003-2010	103,829	192,707	1,192	119,919	670
	2010-2015	17,021	84,264	487	7,000	932
	2015-2020	2,714	33,636	577	7,173	357
5	2003-2010	29,266	29,808	931	2,538	522
	2010-2015	20,328	13,747	573	2,893	396
	2015-2020	8,004	7,511	172	622	33
6	2003-2010	16,020	48,079	250	49,259	268
	2010-2015	8,975	15,658	310	4,481	61
	2015-2020	3,059	10,947	332	3,019	80
7	2003-2010	15,794	15,389	647	7,607	19
	2010-2015	4,064	18,839	513	302	74
	2015-2020	2,716	6,390	285	1,089	37
8	2003-2010	51,836	37,576	556	22,345	224
	2010-2015	25,598	31,453	570	1,274	185
	2015-2020	7,051	14,309	306	1,670	74
9	2003-2010	21,983	12,655	218	20,496	140
	2010-2015	15,447	17,959	169	2,971	46
	2015-2020	3,285	10,983	443	2,339	37
10	2003-2010	23,609	24,172	156	12,473	3
	2010-2015	10,350	28,133	508	8,334	60
	2015-2020	3,425	14,822	469	4,819	100
11	2003-2010	9,895	32,222	93	14,900	28
	2010-2015	6,631	61,353	283	5,414	443
	2015-2020	2,284	18,009	284	1,574	157
12	2003-2010	22,266	47,002	107	57,075	26

Table 2. (Con't)

Region	Period	Agriculture	Brush/ Shrubs	Built-up	Grassland	Open/ Barren
	2010-2015	2,226	16,869	113	3,084	12
	2015-2020	1,858	10,460	274	1,997	21
13	2003-2010	20,751	49,070	853	22,038	448
	2010-2015	8,628	49,435	481	1,560	643
	2015-2020	5,203	39,458	667	3,913	776
ARMM	2003-2010	13,761	11,855	107	4,684	91
	2010-2015	8,622	19,457	205	4,579	344
	2015-2020	3,061	9,784	166	2,199	620

Table 3. Frequency of broad proximate causes of deforestation in the Philippines.

Causation	**Abs (N=130)**	**Rel (%)**
Single-factor	45	
Agricultural expansion (Agro)	19	15
Wood extraction (Wood)	12	9
Infrastructure extension (Infra)	13	10
Other[a]	1	1
Two-factor	60	
Agro-wood	45	35
Agro-infra	6	5
Agro-other		
Wood-infra	5	4
Wood-other	2	2
Infra-other	1	1
Three-factor	21	
Agro-wood-infra	13	10
Agro-wood-other	8	6
Agro-infra-other		
Wood-infra-other		
Four-factor (All)	3	2
Unspecified	1	1
Total	130	100

Note: Abs=absolute frequency, Rel=relative percentage;
[a]Others such as fires, typhoons, landslides, floods, and climate chang

landlessness, and lack of opportunities in the lowlands led to upland migration. Governance, policy, and institutional factors also drove demographic and poverty factors (11%), such as policies favoring commercial agriculture deprived smallholder farmers of their lands, eventually leading to upland migration. Logging bans also displaced many workers, which contributed to poverty, and they remained in the upland to practice upland agriculture and timber poaching.

Table 4. Frequency of specific proximate causes of deforestation in the Philippines.

Specific proximate cause		Abs (N=130)	Rel (%)
Agricultural expansion		78	
Upland agriculture		67	52
	Commercial agriculture	19	15
	Expansion of pastureland	2	2
Infrastructure extension		51	
	Mining	15	12
	Settlement	13	10
	Roads	10	8
	Urbanization	7	5
	Public service	4	3
	Tourism infrastructure	2	2
Wood extraction		82	
	Commercial logging	62	48
	Illegal logging	35	27
	Woodfuel collection	23	18
Other factors		14	
	Fires	13	10
	Typhoons, landslides, flood	4	3
	Climate change	1	1

Note: Abs=absolute frequency, multiple counts possible; Rel=relative frequency, relative to the total number of papers (N=130). Multiple counts were allowed in each paper as papers mention numerous particular causes.
[a]Includes shifting cultivation and smallholder agriculture.
[b]Includes fuelwood and charcoal.

The feedback loop among proximate causes was mostly seen in wood extraction, opening the forest for agricultural expansion (13%).

The feedback of proximate causes to underlying causes was also evident. Most papers cited wood extraction affecting demographic and poverty factors (9%), market demand, and economic development (4%). Commercial logging brought workers inside the forest, eventually contributing to upland migration. The construction of logging roads also encouraged upland migration and improved access to markets and urban centers.

The temporal analysis (**Figure 2**) of the causes of deforestation revealed changes in the most important cause over time. It is evident in Figure 2 that wood extraction and agricultural expansion were the most cited causes of deforestation from 1980 to 1999. The number of papers mentioning wood extraction has significantly declined starting 2000, but agricultural expansion remained a significant cause of deforestation. From 2000, the rise of papers mentioning infrastructure extension as a cause of deforestation was observed. It is now one of the most cited proximate causes of deforestation and agricultural expansion.

DISCUSSION

Comparative analysis of forest cover estimates

There is no agreement on the forest cover of the Philippines. The variations in forest cover estimates can be attributed to their definition of forest, data used, and methodology. Very often, the increase in forest cover from 1997 to 2003 in PFS is attributed to the government's efforts to restore degraded forests in the country (*e.g.*, FAO, 2006). Although there are reforestation projects all over the country, the abrupt increase in forest cover from 1997 to 2003 may be due to the change in the definition of forest from a minimum of 1 ha to 0.5 ha in 2003 to have the same definition of forest with FAO. Starting in FRA 2000, the FAO adopted a new minimum forest area from 100 ha to 0.5, which also explains the variations among various editions of FRA. These changes in the definition of forest have increased areas that can be classified as forests and may not necessarily imply an increase in forest cover.

The spatial resolution of remote sensing images used in classifying land cover also affects the accuracy of the estimates. This is evident in Estoque *et al.* (2018), where various remote sensing products with varying resolutions were used to estimate the forest cover of the Philippines and yielded different results.

In 2002, the ESSC conducted a national land cover mapping following the approach of NAMRIA in 2003. Still, the results yielded more than a 1 M ha

Table 5. Frequency of broad underlying causes of deforestation in the Philippines.

Causation		Abs (N=130)	Rel (%)
Single-factor		49	
	Demographic and poverty factors (Pop)	26	20
	Market demand and economic development (Econ)	12	9
	Technological factors (Tech)	1	1
	Governance, policy, and institutional factors (Gov)	10	8
	Cultural factors (Cult)		
Two-factor		25	
	Pop-econ	7	5
	Pop-tech		
	Pop-gov	12	9
	Pop-cult		
	Econ-tech		
	Econ-gov	4	3
	Econ-cult		
	Tech-gov	1	1
	Tech-cult		
	Gov-cult	1	1
Three-factor		27	
	Pop-econ-tech	1	1
	Pop-econ-gov	20	15
	Pop-econ-cult	1	1
	Pop-tech-gov	1	1
	Pop-tech-cult		
	Pop-gov-cult	3	2
	Econ-tech-gov		
	Econ-tech-cult		
	Econ-gov-cult	1	1
	Tech-gov-cult		
Four-factor		5	
	Pop-econ-tech-gov	3	2
	Pop-econ-tech-cult	1	1
	Pop-econ-gov-cult	1	1
	Pop-tech-gov-cult		

Table 5. (Con't)

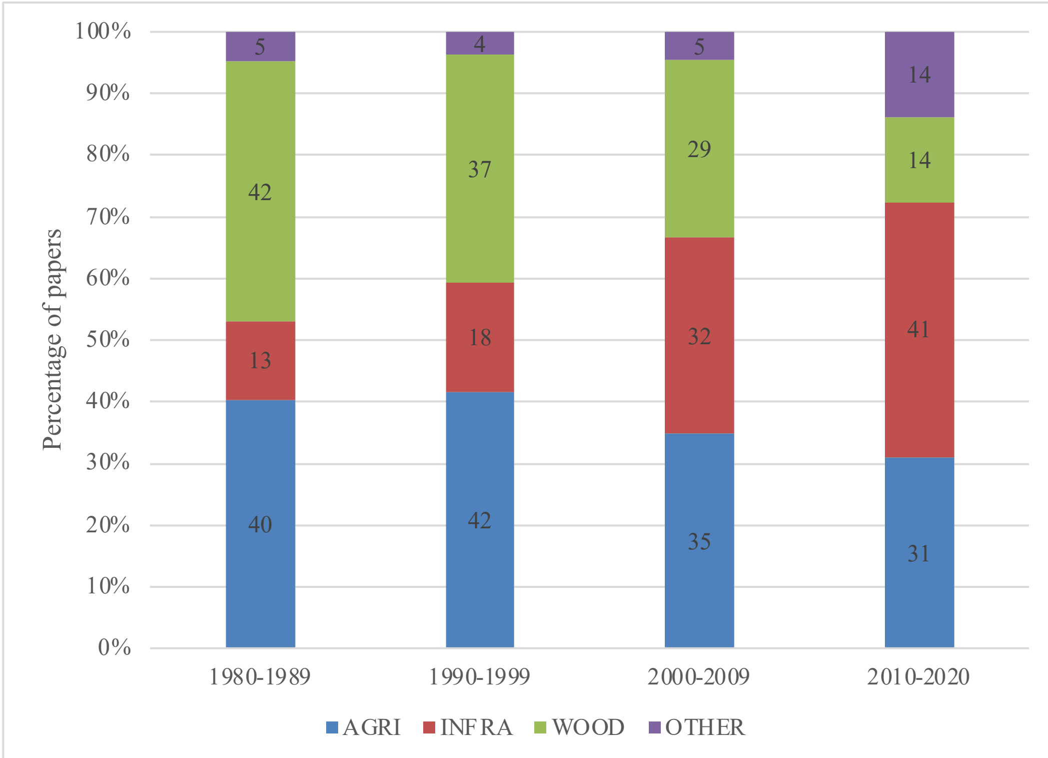
Causation		Abs (N=130)	Rel (%)
Single-factor		49	
	Econ-tech-gov-cult		
Five-factor (All)		2	2
Unspecifie		22	17
Total		130	100

Note: Abs=absolute frequency, multiple counts possible; Rel=relative frequency, relative to the total number of papers (N=130).

Table 6. Frequency of specific underlying causes of deforestation and forest degradation.

Specific underlying cause		Abs (N=130)	Rel (%)
Demographic and poverty factors		76	
	Increase in population	52	40
	Upland migration	37	28
	Poverty	24	18
	Landlessness	18	14
	Unemployment	15	12
Market demand and economic development		52	
	Proximity to market, village, and urban centers	20	15
	Increase in demand	19	15
	Economic growth	9	7
	Industrialization	7	5
	Increase in price	5	4
	Commercialization	5	4
	Low-cost production	1	1
Technological factors		9	
	Use of logging machinery	5	4
	Improved production technologies	3	2
	Chainsaws	2	2
Governance, policy, and institutional factors		60	
	Corruption	28	22
	Poor monitoring and law enforcement	27	21
	Formal policy	22	17
	Political support	13	10
	Property rights	11	8
	Low fees and taxes	10	8
	Lack of policies	4	3
	Unstable and conflicting law	2	2
	External debts	1	1
Cultural factors		7	
	Attitude	6	5
	Lack of awareness	2	2

Note: Abs=absolute frequency, multiple counts possible; Rel=relative frequency, relative to each category.



Note: AGRI – agricultural expansion; INFRA – infrastructure extension; WOOD – wood extraction; OTHER – other factors such as fires, floods, typhoons, landslides, and climate change.

Figure 2. Number of papers discussing the different broad proximate causes across four periods.

difference. These differences may be due to the subjective judgment of the classifier (Weiers *et al.*, 2002). Image interpretation is subject to the biases of the interpreter. Thus, the results in land cover classification may still be different.

Despite the differences in forest cover estimates, the general trend of Philippine forest cover from 2010 to 2020 shows a slow increase in forest cover, which supports the findings of some studies (Matthews *et al.*, 2010; Youn *et al.*, 2017; Liu *et al.*, 2017) where the country is already at the post-transition stage. It has reached the point of increasing forest cover through reforestation (Hosonuma *et al.*, 2012).

Causes of deforestation

Mapping the causes of deforestation in the Philippines shows the complexity of deforestation in the country. Multiple factors cause deforestation, and they also vary across the country. It is caused mainly by the tandem of agricultural expansion and wood extraction. Specifically, it is caused by upland agriculture, commercial logging, and timber poaching. The cross-tabulation of land cover maps revealed that agricultural expansion is mostly in Regions 2, 4B, 5, 8, 13, and CAR. This coincides with the study sites of papers mentioning agricultural expansion, which include Nueva Vizcaya, Oriental Mindoro (Lasco *et al.*, 2001), Palawan (Dressler *et al.*, 2018), and CAR (Prill-brett, 1994; Carandang *et al.*, 2013). Meanwhile, the large forested areas converted to brush/shrub may not be entirely attributed to wood extraction as not all areas with a high transition to brush/shrub has high log production (DENR-FMB, 2021).

Regarding underlying causes, most papers cite demographic and poverty factors, whereas most papers relate deforestation to the increase in population. The interactions of the different proximate and underlying causes are also evident in the papers. Expectedly, underlying causes drive proximate causes, where one underlying cause drives two to three proximate causes. Agricultural expansion is driven mainly by demographic and poverty factors. In contrast, wood extraction is mainly driven by governance and institutional factors. The reverse (*i.e.*, proximate causes driving underlying causes) is also seen in some papers. Commercial logging contributed to upland migration by bringing people into the forest and building road networks inside the forest. Also, feedback is observed within broad proximate and underlying causes. Demographic and poverty factors such as upland migration and increasing upland population affect each other. Commercial logging, commercial agriculture, and mining also include the construction of roads. These show that deforestation in the country is not caused by a single factor but by a complex relationship of different proximate and underlying causes.

The temporal analysis of the causes of deforestation and cross-tabulation of land cover maps shows the changing pattern of deforestation through time and across the country. The decrease in papers mentioning wood extraction as a cause of deforestation may be attributed to the expiration of wood companies' Timber License Agreements (TLAs). Most of the reported cases of deforestation are from TLA holders (*e.g.*, Carandang *et al.*, 2013; van den Top, 2003; Lasco *et al.*, 2001). Since no more TLAs were issued after 1987, recent papers focused on post-logging drivers of deforestation, such as forest migrants converting logged-over areas into upland agriculture (Carandang *et al.*, 2013) and displaced logging company workers conducting illegal logging (Hayama, 2000; van den Top, 2003). TLAs were replaced by new tenurial instruments, which include Integrated Forest Management Agreement (IFMA), Socialized Forest Management Agreement (SIFMA), and Community-Based Forest Management Agreement (CBFMA) (Bugayong, 2006). However, no studies assess these new instruments' effectiveness in addressing deforestation.

Agricultural expansion remains a significant cause of deforestation. This is because the Philippines is still an agricultural country, and there are plans to expand, especially its oil palm plantations (Carandang *et al.*, 2011; Villanueva, 2011; Philippine Palm Oil Industry Road Map 2014-2023). With the increasing population, the demand for food will continue to rise and may be at the expense of forested areas (Lapniten, 2020). The increase in the significance of infrastructure extension may be attributed to accelerating infrastructure development in the country and increased demand for housing. Expansion of roads and expressways may lead to opening forested areas and encourage migration and encroachment (Baehr *et al.*, 2021). Deforestation in the Philippines has already changed from wood extraction dominated in the 18th century to agricultural expansion and infrastructure extension, and policy changes played a significant role in this observed evolution of deforestation. With increasing population and economy, it is unavoidable that land resources are utilized through agricultural expansion and infrastructure extension to serve the country's needs. Hence, proper land use planning and land classification and stronger protection of protected areas should be done to ensure the sustainability of various ecosystem services.

Limitations of the study

Literature review studies are subject to publication, quality, discussion, and selection biases (Haddaway *et al.*, 2015). Publication, quality, and discussion biases are inherent in the papers reviewed. Since the papers reviewed are from peer-reviewed journals and books, the author believes the papers are already reviewed against biases before publication.

In addition, this study is also subject to author biases. Since the sole author conducted the study, no consistency checks were conducted. Most of the papers also consider deforestation and forest degradation. This study focuses on deforestation only, and there were difficulties in distinguishing the drivers of deforestation and forest degradation from the papers. Although the Geist & Lambin (2002) framework was used to help identify the causes of deforestation, some causes were not included as the author thinks they do not fit the definition of deforestation (FAO, 2012). For instance, the extraction of non-wood forest resources (*e.g.*, rattan, bamboo, almaciga resin, wild honey, vines, medicinal plants, and fauna) does not necessarily lead to deforestation because they do not involve wide forest clearances (*i.e.*, Callo, 1995; Eder, 2006). Also, pests and diseases are not included as only selected species are affected, which does not necessarily lead to deforestation (*i.e.*, Briones *et al.*, 2017). Meanwhile, illegal logging and wood fuel extraction are still included in the analysis of causes of deforestation despite their minimal impact on forest cover because of the many papers mentioning them.

CONCLUSION

This study collated forest cover estimates of the Philippines from 1980 to 2020 from various sources such as the DENR, FAO, and independent studies. The different sources have varying estimates of forest cover due to varying data, methodology, and definitions of forest used. These differences made comparison and computation of deforestation rates difficult. Despite the differences in the forest cover estimates, the general trend of forest cover from 2010 to 2020 is slowly increasing.

The analysis of the causes of deforestation also reveals that deforestation in the Philippines is caused by multiple factors, mainly agricultural expansion and wood extraction. Specifically, upland agriculture and commercial and illegal logging are the leading proximate causes. In terms of underlying causes, this study shows that deforestation is not only driven by demographic and poverty factors. It is also driven by governance, policy, and institutional factors, such as corruption, poor monitoring and law enforcement, formal policy, market demand, and economic development, such as proximity to market, village, and urban centers and increase in demand. Further, this study has shown the relationships between the various causes of deforestation. It reveals that underlying causes and vice versa drive proximate causes. There are also interactions between proximate and underlying causes.

Temporal analysis of the causes of deforestation and cross-tabulation of land cover maps revealed the increasing relevance of agricultural expansion and infrastructure extension as causes of deforestation. Thus, it is recommended to have proper land use planning and land classification and stronger protection of protected areas to ensure the sustainability of the various ecosystem services. Future studies may validate the importance of wood extraction, especially in areas under tenurial agreements, as a driver of deforestation. The huge areas transitioning to brush/shrub should also be investigated to determine the causes of such change.

ACKNOWLEDGMENTS

The author is thankful for Dr. Christian Pilegaard Hansen's contribution to supervising her during this study as part of her master's thesis at the University of Copenhagen, Denmark. Also, to Dr. Øystein Juul Nielsen for his valuable comments to improve the study.

LITERATURE CITED

Acosta, R. T. (1989). The Philippines forestation program. *Canopy*, *15*(3), 1–7.

Baehr, C., Benyishay, A., & Parks, B. (2021). Linking local infrastructure development and deforestation: Evidence from satellite and administrative data. *Journal of the Association of Environmental and Resource Economists*, *8*(2), 375–409.

Bankoff, G. (2007). One island too many: reappraising the extent of deforestation in the Philippines prior to 1946. *Journal of Historical Geography*, 33(2), 314–334.

Bee, J. (1987). Depletion of the Forest Resources in the Philippines.

Briones, R. U., Tadiosa, E. R., & Manila, A. C. (2017). Threats on the natural stand of Philippine Teak along Verde Island Passage Marine Corridor (VIPMC), Southern Luzon, Philippines. *Journal of Environmental Science and Management*, **20**(2), 54–67.

Bugayong, L. A. (2006). Effectiveness of logging ban policies in protecting the remaining natural forests of the Philippines. In: *Proceedings of the 2006 Berlin Conference on Human Dimensions of Global Environmental Change—Resource Policies: Effectiveness Efficiency, and Equity*. Berlin, Germany, 17–18.

Callo, R. (1995). Damage to Almaciga Resources in Puerto Princesa and Roxas, Palawan concessions. Laguna, Philippines.

Carandang, A. P., Bugayong, L. A., Dolom, P. C., Garcia, L. N., Villanueva, M. M. B., Espiritu, N.O. & Forest Development Center. (2013). Analysis of Key Drivers of Deforestation and Forest Degradation in the Philippines. Manila, Philippines.

Carter, J. (1999). Recent Experience in Collaborative Forest Management Approaches: A Review of Key Issues. Washington, D.C.

DENR-FMB [Department of Environment and Natural Resources – Forest Management Bureau]. (2021). Philippine Forestry Statistics 2021. Retrieved from: <https://drive.google.com/file/d/1V2JS74-DPvMc4A8r3AJwrMDoAmXptI9f/view>.

Dressler, W. H., Smith, W., & Montefrio, M. J. F. (2018). Ungovernable? The vital natures of swidden assemblages in an upland frontier. *Journal of Rural Studies*, *61*, 343–354.

Eder, J. F. (2006). Land use and economic change in the post-frontier upland Philippines. Land Degradation & Development, 17(2), 149–158.

Estoque, R. C., Pontius Jr, R. G., Murayama, Y., Hou, H., Thapa, R. B., Lasco, R. D., & Villar, M. A. (2018). Simultaneous comparison and assessment of eight remotely sensed maps of Philippine forests. *International Journal of Applied Earth Observation and Geoinformation*, *67*, 123–134.

Executive No. 23, s. 2011. Retrieved from: <https://www.officialgazette.gov.ph/2011/02/01/executive-order-no-23-s-2011/>.

Executive Order No. 26, s. 2011. <https://www.officialgazette.gov.ph/2011/02/24/executive-order-no-26-s-2011/>.

FAO [Food and Agriculture Organization of the United Nations]. (2006). Global forest resources assessment 2005: Progress towards sustainable forest management. *FAO Forestry Paper 147*. Rome, Italy.

FAO [Food and Agriculture Organization of the United Nations]. (2012). FRA 2015 terms and definitions. Rome, Italy, No. 180.

FAO [Food and Agriculture Organization of the United Nations]. (2016). Global Forest Resources Assessment (2nd ed.). Rome, Italy.

FAO [Food and Agriculture Organization of the United Nations]. (2020). Global forest resources assessment 2020. Rome, Italy.

Geist, H. J. & Lambin, E. F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience*, 52(2), 143–150.

Haddaway, N. R., Woodcock, P., Macura, B., & Collins, A. (2015). Making literature reviews more reliable through the application of lessons from systematic reviews. *Conservation Biology*, 29(6), 1596–1605.

Hance, J. (2011). Philippines Disaster May Have Been Worsened by Climate Change, Deforestation. Retrieved from: <https://news.mongabay.com/2011/12/philippines-disaster-may-have-been-worsened-by-climate-change-deforestation/>.

Hayama, A. (2000). Transforming interaction of the local people with the uplands: A case study in Southeastern Nueva Ecija, Central Luzon. *Southeast Asian Studies*, *37* (4), 458–491.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*.

Hughes, A. C. (2017). Understanding the drivers of Southeast Asian biodiversity loss. *Ecosphere*, 8(1).

IUCN [International Union for Conservation of Nature]. (2017). Deforestation and Forest Degradation. Gland, Switzerland.

Kummer, D. M. (1992). Deforestation in the Postwar Philippines. The University of Chicago Press.

Lapniten, K. (2020). Averting an Agricultural and Ecological Crisis in the Philippines' Salad Bowl. Mongabay. Retrieved from: <https://news.mongabay.com/2020/03/averting-an-

agricultural-and-ecological-crisis-in-the-philippines-salad-bowl/>.

Lindberg, K., Furze, B., Staff, M., & Black, R. (1997). Asia-Pacific Forestry Sector Outlook Study: Ecotourism and Other Services Derived from Forests in the Asia-Pacific Region: Outlook to 2010. Rome, Italy and Bangkok, Thailand.

Lasco, R. D., Visco, R. G., & Pulhin, J. M. (2001). Secondary forests in the Philippines: Formation and transformation in the 20th century. *Journal of Tropical Forest Science*, *13* (4), 652–670.

Liu, D. S., Iverson, L. R., & Brown, S. (1993). Rates and patterns of deforestation in the Philippines: Application of geographic information system analysis. *Forest Ecology and Management*, *57*, 1–16.

Liu, J., Liang, M., Li, L., Long, H., & De Jong, W. (2017). Comparative study of the forest transition pathways of nine Asia-Pacific countries. *Forest Policy and Economics*, *76*, 25–34.

Matthews, R., Swallow, B., Van Noordwijk, M., Milne, E., Minang, P., Bakam, I., Brewer, M., Muhammed, S., Poggio, L., Glenk, K., Fiorini, S., Dewi, S., Xu, J.C., Cerbu, G., & Subedi, M. (2010). Development and Application of Methodologies for Reduced Emissions from Deforestation and Forest Degradation (REDD+) - Phase I. London, United Kingdom.

Nabuurs, G. J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W. A., Matsumoto, M., Oyhantcabal, W., Ravindranath, N. H., Sanchez, M. J., & Zhang, X. (2007). Forestry. *In*: Metz, B., Davidson, O.R., Bosch, P. R., Dave, R., & Meyer, L. A. (eds.), *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 543-578. Cambridge University Press.

Pang, S. E. H., De Alban, J. D. T., & Webb, E. L. (2021). Effects of climate change and land cover on the distributions of a critical tree family in the Philippines. *Scientific Reports*, 11(1), 276.

Perez, G. J., Comiso, J. C., Aragones, V. L., Merida, H. C., & Ong, P. S. (2020). Reforestation and deforestation in Northern Luzon, Philippines: Critical issues as observed from space. *Forests*, *11*(10).

The Philippine Palm Oil Industry Roadmap 2014-2023. Retrieved from: <http://www.mpoc.org.my/upload/pots_philippines_palm_oil_industry_road_map.pdf>.

Prill-brett, J. (1994). Indigenous land rights and legal pluralism among Philippine highlanders. *Law & Society Review*, *28* (3), 687–698.

The Philippines REDD-plus Strategy Team. (2010). The Philippine National REDD-Plus Strategy. Philippines.

van den Top, G. (2003). Social Dynamics of Deforestation in the Philippines: Actions, Options, and Motivations. Nordic Institute of Asian Studies.

Villanueva, J. (2011). Oil palm expansion in the Philippines: analysis of land rights, environment, and food security issues. *In:* M. Colchester and S. Chao, eds. *Oil Palm Expansion in South East Asia: Trends and implications for local communities and indigenous peoples*. Forest Peoples Programme and Perkumpulan Sawit Watch, 110–216.

Wallace, B. J. (2011). Village-based illegal logging in Northern Luzon. *Asia-Pacific Social Science Review*, *11* (2), 19–26.

Walpole, P. (2011). Low Forest Cover in the Philippines: Issues and Responses at the Community Level. Environmental Science for Social Change, Inc. Retrieved from: <https://essc.org.ph/content/lview/579/1/>.

Weiers, S., Groom, G., & Wissen, M. (2002). Comparability and subjectivity of land cover maps produced with digital image classification techniques: Some recent experiences from Denmark and Northern Germany. Geografisk *Tidsskrift-Danish Journal of Geography*, *102*(1), 59–77.

Wertz, K. & Kongphan, A. (2008). Reducing forest emissions in Southeast Asia: A review of drivers of land-use change and how payments for environmental services (PES) schemes can affect them.

World Bank. (1989). Philippines: Environment and Natural Resource Management Study. Washington, D.C., USA.

Youn, Y. C., Choi, J., De Jong, W., Liu, J., Park, M. S., Camacho, L. D., Tachibana, S., Huudung, N. D., Bhojvaid, P. P., Damayanti, E. K., Wanneng, P., & Othman, M. S. (2017). Conditions of forest transition in Asian countries. *Forest Policy and Economics*, *76*, 14–24.

p-ISSN 2012-3612 │ e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 │ Number 1 │ pp. 33–46│ 2023

Impact assessment of road development on forest cover in the Upper Marikina Watershed, Philippines

Tricia Joy E. Castañeda[1*], Diomedes A. Racelis[1]

[1]*College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. Most watersheds in the Philippines are already in critical condition. One of which is the Upper Marikina Watershed (UMW), where forest cover has dwindled significantly due to land conversion as well as land use and land cover change. Road networks are being developed as a means of access and transportation to land-converted areas. However, roads are a major driver of deforestation and degradation. Therefore, this study assessed the impacts of road development on forest cover in the UMW. Specifically, it determined the extent of the road network in the watershed; described the extent of forest cover in the watershed in 2005, 2010, 2015, and 2020; analyzed changes in the forest cover of the watershed through time; and established the relationship between road network development and the changes in forest cover in the watershed. Shapefiles from the National Mapping and Resource Information Authority (NAMRIA) and 2020 Landsat 8 satellite images were used to generate 2005, 2010, and 2015 land cover maps to detect changes over time. The Landsat 8 satellite image was processed for image pre-processing, cloud masking, sub-setting, image classification, and accuracy assessment through remote sensing using the QGIS software and the Semi-Automatic Classification Plugin. The data on the forest cover of the site through 2005, 2010, 2015, and 2020 were analyzed through Change Detection Analysis. This analysis was used in correlation with the existing road network within the watershed. The findings revealed a significant decrease in forest cover in the UMW between 2005 and 2020. All these changes in forest cover due to further land conversion in the area create opportunities for road network development and expansion, which are inversely correlated with forest changes.

Keywords: GIS, image classification, landsat satellite image, remote sensing, semi-automatic classification plugin

Article Information
Received 28 July 2022
Accepted 21 February 2023
Published online 16 October 2023
*Email: tecastaneda@up.edu.ph

INTRODUCTION

A watershed is a land area drained by a stream or fixed body of water and its tributaries having a common outlet for surface run-off (DENR, 2017). It is a functional and integrated system that provides goods and services, such as food, water, medicine, fibers, timber, and non-timber products, vital to the welfare and security of local communities.

Watersheds of various sizes are estimated to cover at least 70% of the total land area of the Philippines. Watersheds with an area of at least 100,000 ha, known as river basins, account for more than 10 M ha of the watershed area. Watershed reserves have been designated for various purposes, such as domestic water supply, irrigation, hydroelectric power generation, and multiple uses. Watersheds are valuable not only for their water resources but also for the forests and other natural resources. Watershed management is thus critical in promoting the sustainability of all-natural resources in the watersheds (DENR, 2015). Most watersheds in the Philippines are already in critical condition. Degraded forests, soil erosion, erratic streamflow, declining groundwater resource, loss of biodiversity, microclimate deterioration, and declining land productivity characterize many of the country's watersheds. Deforestation contributes significantly to the degradation of nearly 2.6 M ha of the country's identified critical watershed areas (Paragas *et al*., n.d.).

Moreover, most watersheds in the Philippines are under threat due to increasing economic activities associated with the growing population. Destructive activities such as land conversion, agricultural expansion, and road development lead to deforestation and forest degradation in the upstream portion of the watershed, which causes water pollution, mudslides, landslides, soil erosion, and flooding in the downstream areas.

Forest cover in the Philippines has drastically decreased over the past decades. About 1.2 M ha of tree cover with a 30% threshold was lost from 2001 to 2020, or an annual loss of 79,534 ha. According to the 2020 Philippine Forestry Statistics, about 15 M ha or 52.68% of the country's total land area is classified as forestland.

The Upper Marikina River Basin Protected Landscape (UMRBPL) is a protected area in the Philippines that constitute the UMW and was established in 2001 by Presidential Proclamation 296 and covers a total land area of 26,126 ha. Antipolo City, Baras, General Nakar, Rodriguez, San Mateo, and Tanay are among the six local government units that benefit from the natural resources in this area. Antipolo (Artocarpus blancoi), Red Lauan (Shorea negrosensis), Yakal (Shorea astylosa, Luzon Bleeding Heart (Gallicolumba luzonica), Rufous Hornbill (Buceros hydrocorax), and Northern Luzon Cloud Rat (Phloeomys pallidus) are all found in this watershed, which is an important front line for biodiversity conservation (DENR, 2015).

Illegal tree cutting, slash-and-burn farming, unsustainable fuel-wood collection, residential and commercial expansion, and forest fires contribute to the UMW's forest and habitat degradation (DENR, 2015). The forest cover in the Marikina Watershed has also dwindled significantly due to land conversion, land use, and land cover change (Abino *et al.*, 2015).

Forest roads are built to improve access to forest areas to support forest management, resource extraction and travel, firefighting, material transit, tourism, national defense, and building renewable energy installations in distant places. However, forest roads are acknowledged to alter the hydrologic response of watersheds (Kastridis, 2020).

The study of Forman & Alexander (1998) and Leonard & Hochuli (2017) found that roads have a wide range of ecological impacts, including habitat destruction, changes in animal behavior, and higher wildlife mortality, and that the result of the rapid proliferation of roads and other infrastructure as mentioned in the study of Laurance *et al.* (2017) was in Africa's tropical forests undergoing unprecedented changes. Furthermore, Poor *et al.* (2019) found that improved forest access along the forest boundary in an endemic ecosystem in Sumatra, Indonesia was attributed to roads, which are a major driver of deforestation and degradation. Unofficial roads go unreported and unrecorded in many tropical areas, leading to inaccurate estimations of wooded areas. The findings of this study indicate that roads and their consequences pose a significant threat to the endemic ecosystem in Sumatra, Indonesia.

Due to the significant decrease of forest cover in UMW, communities in the lowland areas of the watershed are experiencing the negative impacts of forest cover loss as caused by the unregulated exploitation, change of land use, and land conversion in the forests of these watersheds. The increasing population in this area is one factor in the continuous land conversion of these forested areas erasing 47,000 ha of forests yearly

(Yan, 2020). Population growth affects land-use change and patterns (NRC, 1993). Conversion of lands and changing land use addresses the rising demand of an increasing population by establishing industries and infrastructure, *e.g.*, transportation and road development systems, to meet the population's needs.

Due to continued land use change and land conversions in the UMW, road networks have been developed to increase access and facilitate transportation to the area. As a result, the road networks have expanded in tandem with further land conversion within the watershed.

Therefore, this study assessed the impact of road development on forest cover in the UMW by determining the extent of the road network in the watershed in 2005 and 2020, determining the forest cover in the watershed in 2005, 2010, 2015, and 2020, analyzing the changes in the forest cover of the watershed through time, and establishing the relationship between road network development and the changes in forest cover in the UMW.

Addressing one of the existing environmental problems in the country will require determining its causes and impacts. Knowing the causes of forest cover decrease and its impact on the environment and community will help determine how to manage and address this problem properly. The establishment of the relationship between road network development and forest cover will help as a guide in addressing the decreasing forest cover problems in the country. Describing the impacts of the road network developments and establishing their relationship to the forest cover will aid in providing the best solution for managing the watershed in terms of crafting policies on land-use change and conversion, proper utilization of forest resources, and strengthening existing policies.

METHODOLOGY

This study focused on establishing the relationship between road development and forest cover in the UMW by generating road network and land cover maps of the watershed in different years (2005, 2010, 2015, and 2020).

Study site

The UMW covers 27,952 ha through the municipalities of Antipolo, Baras, Rodriguez, San Mateo, and Tanay (Olchondra, 2012) (**Figure 1**). The Marikina River is dammed in Rodriguez by Wawa Dam, a structure built in the early 1900s to provide water for Manila. It flows approximately 11 km through the center of the province. It has several tributaries in creeks and rivers, draining four municipalities and one city in the province of Rizal, as well as three cities in the National Capital Region (NCR), the largest of which is upstream in the more mountainous areas of Rodriguez. The Tayabasan and Montalban, the Boso Boso River, and the Wawa Rivers, which meet the Marikina River just upstream of Wawa Dam, are included. The Puray and Manga Rivers are located downstream of the dam but within Rodriguez (David & Pellejera, 2011).

The UMRBPL is a protected area in the Rizal Province that encompasses the UMW. "Marikina Watershed" is sometimes used to refer to this protected area. However, it also refers to the river's entire drainage basin, stretching from Rizal Province's Sierra Madre Mountains to Pasig's Napindan area, emptying into the Pasig River. The Marikina Watershed Reservation was the name of the UMRBPL until November 2011, when President Benigno S. Aquino III upgraded its status from "reservation" to "protected landscape."

Data collection

This study utilized the shapefiles provided by the National Mapping and Resource Information Authority (NAMRIA) and the satellite image from the United States Geological Survey (USGS). The shapefile obtained from NAMRIA including the road centerline shapefile was used to define the extent of road network development within the study site, along with the varying land cover classes of the study site in 2003, 2010, and 2015, as well as the satellite image extracted from the Earth Explorer USGS for 2020. Furthermore, this study used the 2004 road network data from the Department of Environment and Natural

Resources (DENR) as the benchmark for 2005 and the 2018 road network data from the NAMRIA as the benchmark for 2020 in determining the trend of forest cover change over time. The 2003 land cover shape file was the benchmark for 2005 to establish a 5-year gap within periods.

Data processing

The shapefiles from NAMRIA and DENR were processed in QGIS version 3.16.15 to generate the land cover map for 2005, 2010, and 2015 and the road network map for 2005 and 2020. The extent of each class per year was identified and compiled for documentation. The 2020 satellite image acquired was processed and classified through remote sensing using the QGIS software and the Semi-Automatic Classification Plugin (SCP).

Image pre-processing

The satellite image was calibrated using radiometric correction techniques from the SCP plugin in QGIS. The satellite image that was remotely sensed was delivered as calibrated Digital Numbers (D.N.), and the conversion to Top of Atmosphere (TOA) reflectance and brightness temperature was performed. The natural color was the band combination used for the Landsat 8 satellite image. It was generated by matching the corresponding wavelength of the bands to the colors of band rendering – red, green, and blue to bands 4, bands 3, and bands 2, respectively.

Cloud masking and sub-setting

Cloud masking was done to remove the existence of clouds in the satellite image scene through the SCP plugin. The image was reclassified to determine and extract the clouds. Stitching the clouded areas on the satellite image was done using the same pre-processed Landsat image classification dated January 2020. Because the

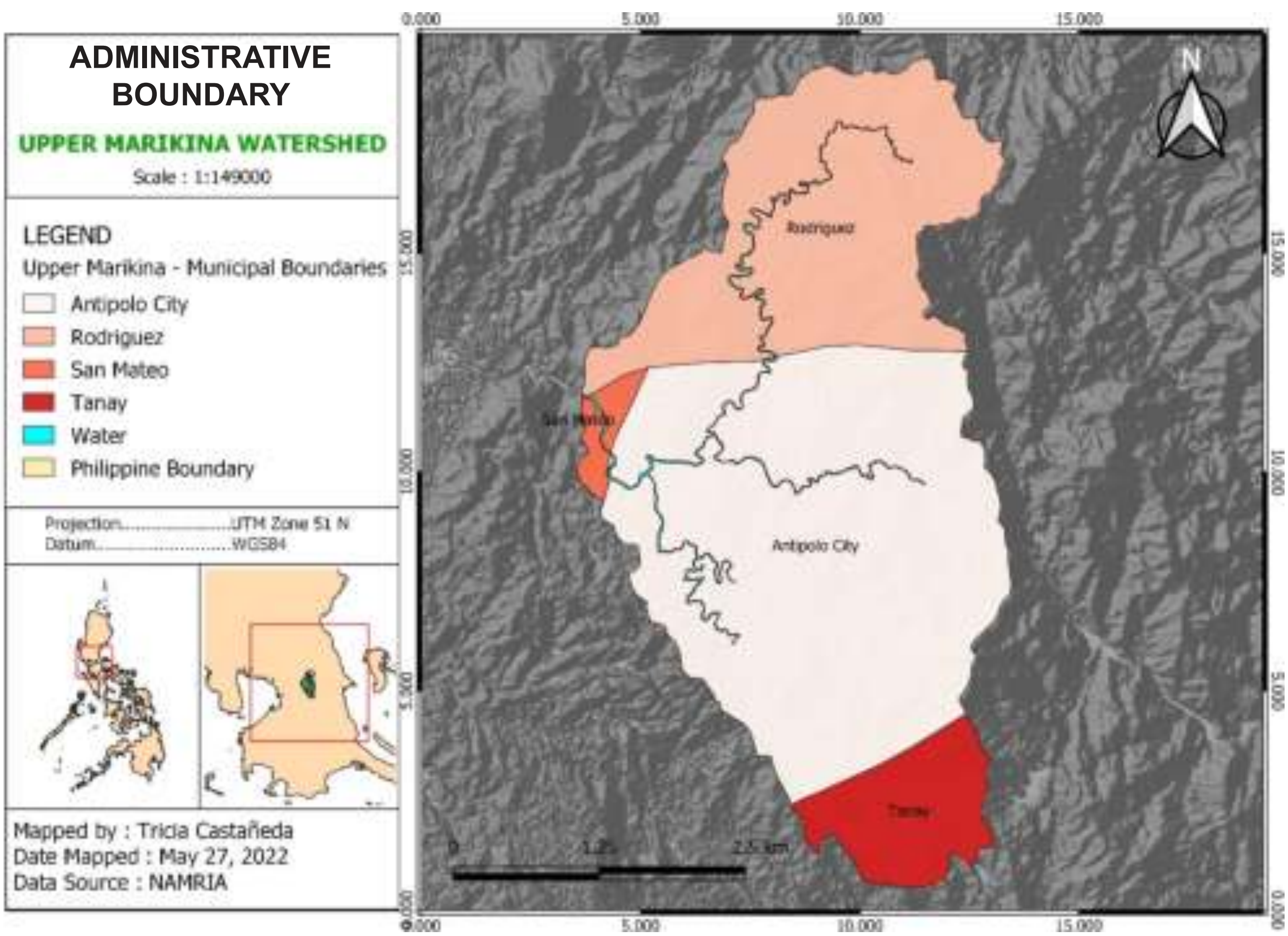


Figure 1. Administrative boundary map of Upper Marikina Watershed.

Landsat scenes are much larger than the study area, the images were cropped or subset to include only the area of interest, the UMW. The clip multiple raster tool of the SCP plugin was used in clipping the site's boundary on the pre-processed satellite image scene. As a result, unrelated data was removed, and processing was sped up due to the smaller data. Spectral indices using the individual pre-processed bands of the Landsat 8 satellite image were generated using the band calculator. The Normalized Difference Vegetation Index (NDVI) was generated to highlight the greenness of the area.

Image classificatio

Image classification was performed to locate homogeneous pixel data in the remotely sensed image. These pixels were classified according to their land cover/land use. The supervised classification method of image classification was used in this study. The pre-processed image was supervised and classified to produce the various land cover categories in the study area. The band combination of the pre-processed satellite image was set to its natural color. Color composites helped identify features in creating Region of Interests (ROI) representing the classified land cover type. Training inputs were generated for sample pixels to represent the land cover class. This study used five training sets, including at least 20 ROIs in each set, as shown in **Table 2**. Supervised classification was used to group pixels in a dataset into classes corresponding to user-defined training classes based on common characteristics. After generating the training inputs, the minimum distance classification algorithm was used for the image classification process. For this algorithm, no threshold was used. This algorithm was used as it generated a better result than the maximum likelihood and spectral angle algorithm.

Accuracy assessment

Any classification project must include an accuracy assessment. It compares the classified image to data from another source considered accurate or ground truth (ESRI, 2021). The most common method for determining a classified map's accuracy is to generate a set of random points from the ground truth data and compare them to the classified data in a confusion matrix. The creation of a confusion matrix for the classified image was done for this study to demonstrate the accuracy of classification by comparing the results to the ground. Using ground truth ROIs, the confusion matrix was calculated using the SCP plugin. Overall accuracy and kappa coefficient values were reported.

Thirty-nine points or locations in the bounds of the study area in ESRI were identified that served as the ground truth or the reference data matched on the classified satellite image to create the confusion matrix. These ground points were generated as 30% representative of the total ROIs used to classify the satellite image.

Table 2. Number of the region of interests (ROIs) or training inputs used per land cover class.

Land cover	No. of training input
Forests	45
Built-up areas	25
Croplands	25
Water	10
Grassland	20
Total	125

Table 3. Number of ground points used per class.

Land cover	No. of ground points
Forests	14
Built-up areas	8
Croplands	8
Water	3
Grassland	6
Total	39

Data analysis

Forest cover data of the site through 2005, 2010, 2015, and 2020 were analyzed through change detection analysis. This analysis of the forest cover extent through time was used in correlation to the road network development within the watershed from 2005 to 2020. The graphical analysis helped assess the impacts of road network development on the extent of forest cover in the UMW over time.

Change detection analysis

The classified satellite images were used under the Minimum Distance algorithm. The change detection analysis SCP tool provided a simple approach to measuring changes between two classes representing an initial and final state. In this study, 2010 and 2015 were considered initial and final states, whereas 2015 and 2020 were considered the initial and final states, respectively. Three table outputs for change detection resulted from three pairings: 2005 (initial) and 2010 (final), 2010 (initial) and 2015 (final), and 2015 (initial) and 2020. (final). A detailed analysis of the changes in the classified image was performed. The areas were calculated using the land cover classes in different years that were generalized and unified into five main land cover classes identified: forests, built areas, croplands, water, and grasslands.

RESULTS AND DISCUSSION

Road networks in Upper Marikina Watershed

One of the specific objectives of this study is to determine the extent of the road network within the UMW and establish its relationship to the forest cover condition within the watershed through time. **Figure 2** shows a noticeable increase in the road network in the UMW, particularly in Tanay and Antipolo City, from 2005 to 2020. It was calculated that these road networks increased from 163.41 km to 914 km.

Upper Marikina Watershed in 2005

The land cover map of the UMW for 2005 is

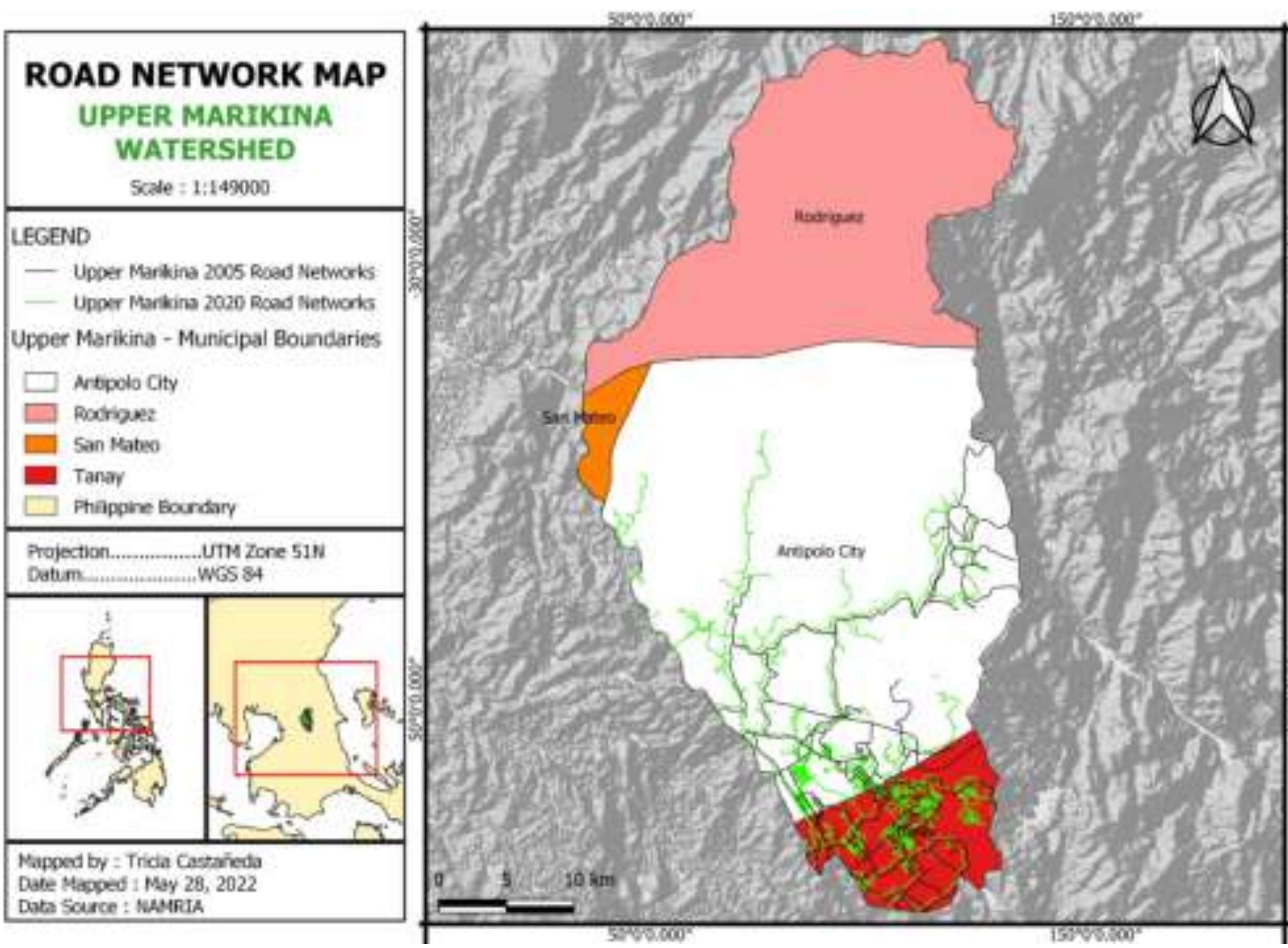


Figure 2. Road network map of Upper Marikina Watershed in 2005 and 2020.

shown in **Figure 3**. This study considered a closed broadleaved forest, open broadleaved forest, and shrubland as part of forested land. About 23,460 ha (about 84%) of land in the watershed was forested in 2005. Other land covers, including built-up areas and grasslands, were considered non-forested, covering about 4,491 ha (16% of the entire UMW). Figure 3 shows a large percentage of forested land in the UMW for 2005. The 0.06% or about 18 ha of built-up areas covering the site is a small number. This greatly contributes to the area's high percentage of forest cover, showing that the site is not yet exploited and degraded.

Upper Marikina Watershed in 2010

The land cover map of the UMW for 2010 is shown in **Figure 4**. This shows that about 55% of the UMW was covered by forested land in 2010. A sum of 15,428 ha of land (45% of the entire UMW) was covered by open and closed broadleaved forest and shrub lands (*i.e.*, built-up areas, annual and perennial croplands, open barren, inland water, and wooded grasslands) that significantly contribute to the low percentage of forest cover in the area.

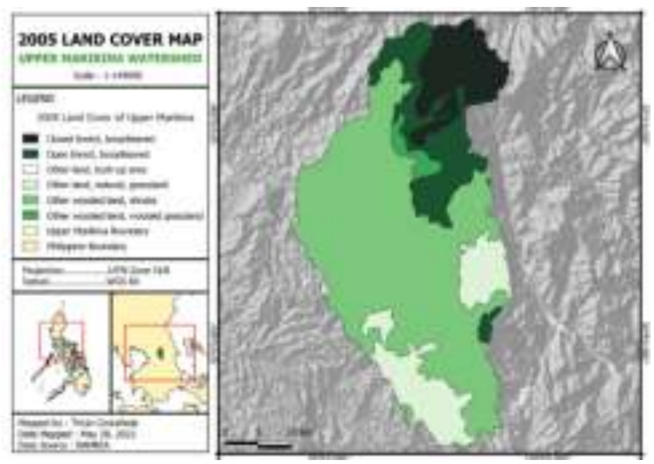


Figure 3. Land cover map of the Upper Marikina Watershed in 2005.

Upper Marikina Watershed in 2015

The land cover map for 2015 is shown in **Figure 5**. A total of 20,791 ha of land in the watershed remain to be covered by open and closed broadleaved forest and shrublands. This shows that about 74% of the UMW was covered by forested land in 2015. About 26% (7,161 ha) of built-up areas, annual and perennial croplands, open barren, inland water, and grasslands covering the site is a large number that significantly contributes to the low percentage of forest cover in the area.

Upper Marikina Watershed in 2020

The land cover map of the UMW for 2020 is shown in **Figure 6**. About only 18,861 ha of land in the watershed remains to be covered by forested lands. This shows that about 67% of the UMW was covered by forested land in 2020. Figure 6 shows a low percentage of forested land in the UMW for 2015. The 33% (9,090 ha) of built-up areas, croplands, inland water, and grasslands covering the site is a large number that greatly contributes to the decrease in the area's forest cover percentage.

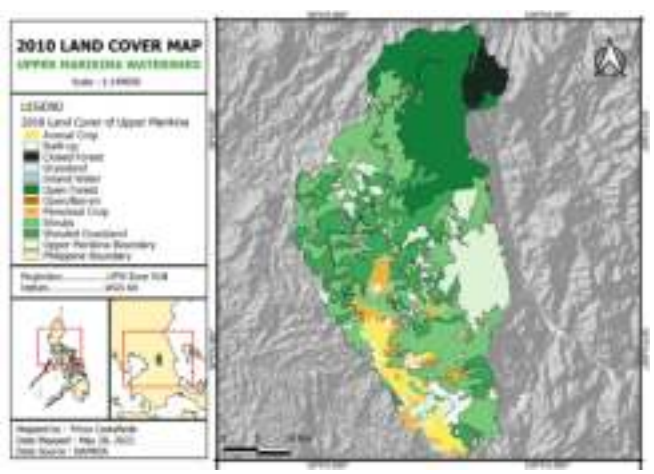


Figure 4. Land cover map of the Upper Marikina Watershed in 2010.

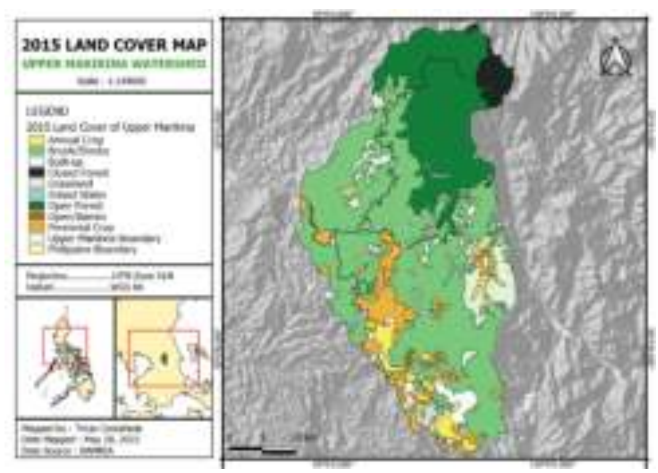


Figure 5. Land cover map of the Upper Marikina Watershed in 2015.

Image processing

Image preprocessing began with atmospheric correction. This allowed the surface reflectance of satellite data to be recovered, significantly improving the image for classification. This step eliminated atmospheric absorption and scattering effects on the scene. The existence of clouds in the satellite image scene was removed through cloud masking, and the same pre-processed satellite image was used to stitch all the clouded areas in the original pre-processed satellite image. **Figure 7** shows the satellite image before and after generating the natural color band combination by matching the corresponding wavelength of the bands to the colors of band rendering – red, green, and blue to bands 4, bands 3, and bands 2, respectively.

Image classificatio

This study used supervised classification to classify the 2020 Landsat 8 image, specifying land cover classes as training data. The satellite data were classified using an algorithm that assigned classes per pixel signatures and divided the land area into five classes. There are at least 20 training sites generated for each land cover class. **Figure 7** depicts land cover thematic maps for the UMW

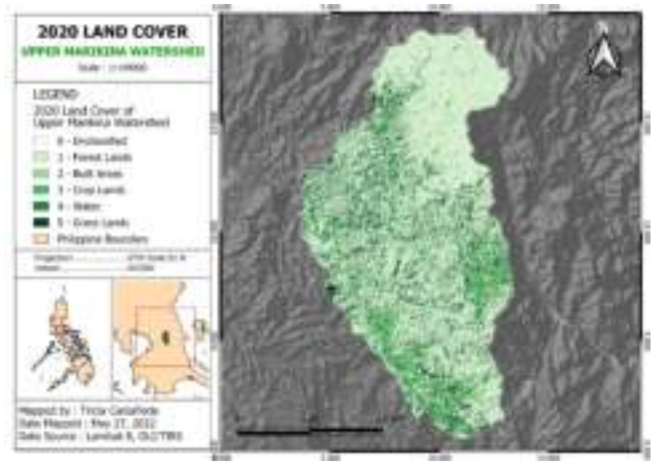


Figure 6. Land cover map of the Upper Marikina Watershed in 2020.

in 2020. Forests, built-up areas, croplands, inland water, and grassland are delineated. The area covered by cloud data that cannot be further classified into a specific land cover is known as the unclassified area. Each class has a distinct identity using different colors to distinguish them. A visual interpretation was used to solve the problem of mixed pixels during classification and made a significant difference in the supervised classification results. This process resulted in thematic maps of the 2020 UMW's land cover.

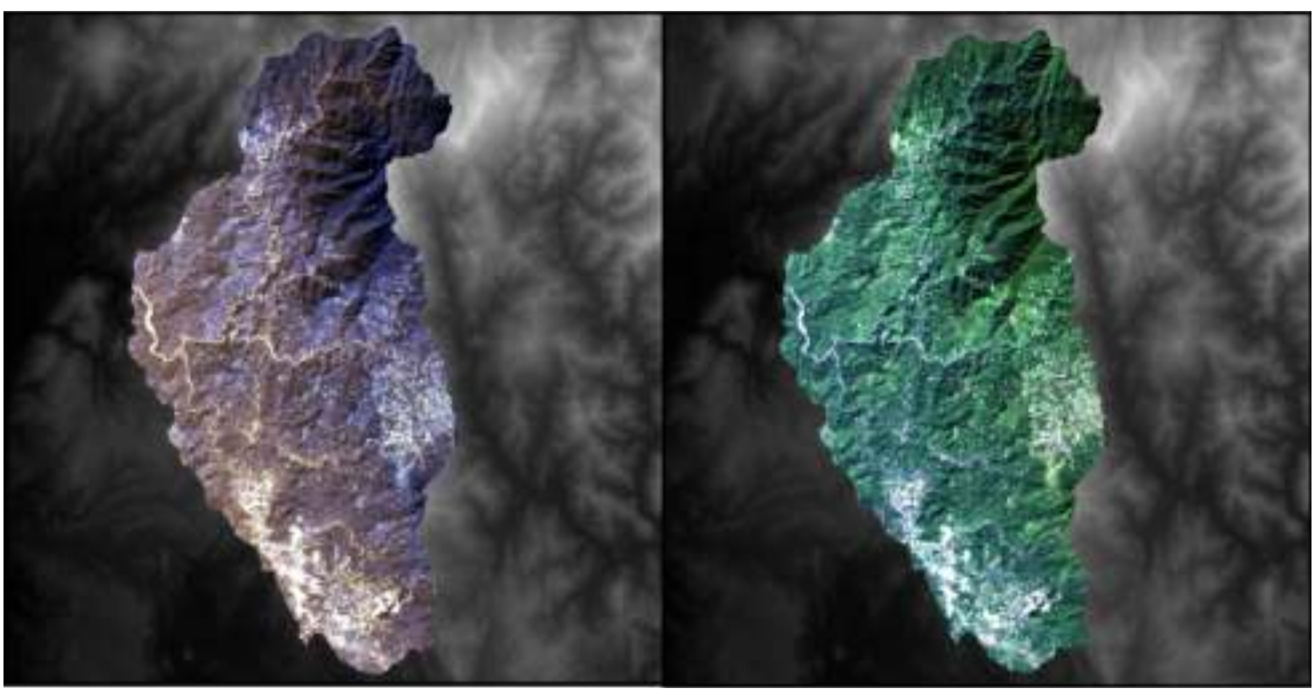


Figure 7. Unprocessed satellite image (left) vs. pre-processed satellite image (right).

The classified image through the minimum distance supervised classification algorithm and the generated NDVI of the pre-processed satellite is shown in **Figure 8**. It also shows the closeness and appropriateness of the computed NDVI and the generated classified satellite image. The NDVI represents the greenness of the study site.

Accuracy assessment

Thirty-nine random training samples (**Figure 9**) were selected for each predetermined land cover type using ESRI's QGIS polygon designation around representative sites. The spectral signatures for the various land cover types were recorded in the pixels enclosed in these polygons. These training samples were used as ground truth data, requiring visual interpretation, and compared to the reference data to determine classification accuracy. The confusion matrix was generated using the 39 ground truth samples, and it calculated the overall accuracy of each classification in 2020. The overall classification accuracy for the minimum distance algorithm in 2020 is shown in **Table 4**. The confusion matrix in the SCP plugin in QGIS was used to assess this.

The assessment of the classified Landsat 8 satellite image yielded an overall accuracy of 54.89% and a kappa hat classification of 0.37 using the minimum distance algorithm of the supervised classification. Specifically, forests or the MC ID 1 yielded 83.82% producer's accuracy, while MC ID 2, 3, and 4 or the built-up area, croplands, and water classes have yielded a 100% producer's accuracy, respectively. MC ID 5, or the grasslands land cover, has yielded a 23.78% producer's accuracy percentage.

Although four out of five classes showed high to perfect accuracy, one class had a very low producer's accuracy, leading to an overall relatively low accuracy in the study due to the small number of classes. The reason for having only five classes was that only forest cover and its changes through time were assessed and not the other land cover classes. Despite a low accuracy assessment percentage of the classified satellite Landsat 8 image, it was still used for the change detection analysis as a forest. The MC ID 1 yielded a reasonably good producer's and user's accuracy percentage.

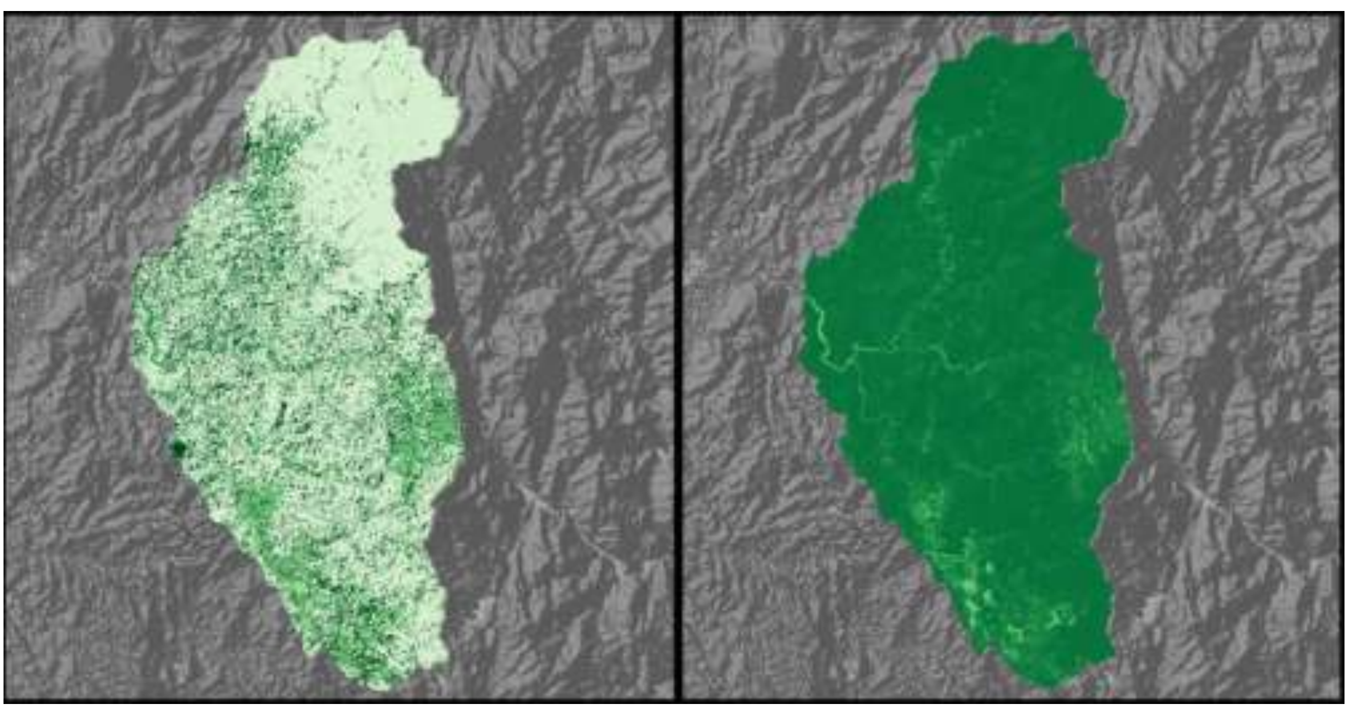


Figure 8. Minimum distance classification of the Landsat 8 satellite image (left) and the calculated NDVI of the satellite image of the site (right).

Table 4. Summary of the accuracy report.

	Reference	MC ID 1	MC ID 2	MC ID 3	MC ID 4	MC ID 5
S.E. area	0	13558	1834	13433	113	0
95% CI area	0	26574	3594	26329	222	0
P.A. [%]	nan	83.82	100	100	100	23.7772
UA [%]	0	100	0.0377	0.1992	0.0054	100
Kappa hat	0	1	0.0004	0.0019	0.0001	1
S.E. area	0	13558	1834	13433	113	0
95% CI area	0	26574	3594	26329	222	0
Overall accuracy [%] = 54.8912						
Kappa hat classification = 0.373						

Change detection analysis

The land cover classes for 2005, 2010, and 2015 from the NAMRIA were harmonized for the change detection analysis (**Table 5**). These harmonized shapefiles from NAMRIA were rasterized and used to detect the forest cover changes through time. Land cover for 2005 was compared to 2010, 2010 to 2015, and 2015 to the classified satellite image of 2020. The change detection analysis report highlighted pixel values that changed from forests to other classes and *vice versa*. **Tables 6** to **8** show the summary of the change detection analysis report.

Forest cover in Upper Marikina Watershed from 2005 to 2020

After the forest cover extent in UMW in different years was defined, its changes every five years were analyzed. **Table 9** shows that UMW's forest cover changed from 2005 to 2020. A 2.35% or about 658 ha out of 27,952 ha of UMW forest increase was recorded from 2005 to 2010, along with a massive decrease of 31.08% or 8,686 ha. From 2010 through 2015, it was found that a 6,477 ha or 23.17% forest increase happened, with a 4% forest decrease or only 1,117.44 ha of forest cover loss. Moreover, a 10.28% forest cover increase happened from 2015 to 2020, or about 2,873 ha, along with a 17.23% or 4,816 ha forest cover decrease in the UMW site.

Assessment of the impact of road network developments on the forest cover in the Upper Marikina Watershed

The data gathered and presented above shows that the forest cover in the UMW has changed over time. These changes were either increased or decreased forest cover (**Figure 10**). From 2005 to 2010, a noticeable change in forest cover was recorded. The massive land conversion in the area contributes to decreased forest cover in the UMW. Along with these land conversions, road networks are developed to open the area for more access to these converted lands. There will always be environmental and social consequences when a road is built. However, Southeast Asia will likely have the least research on these effects among tropical regions. The study by Clements (2013)

Figure 9. Ground truth points to the accuracy assessment of the classified satellite image

Table 9. Summary of the road network and forest cover change through time.

	2005	2010	2015	2020
Amount of forest cover	83.93%	55.20%	74.38%	67.48%
Road network increase	0%	25%	50%	100.00%

Table 5. Land cover classes to be used for change detection analysis.

MC ID	2005	2010	2015	2020
1	Open forest	Open forest	Open forest	Forests
	Closed forest	Closed forest	Closed forest	
	Shrub	Shrub	Brush/Shrub	
2	Built-up areas	Built-up areas	Built-up areas	Built-up areas
3	Croplands	Annual crop	Annual crop	Croplands
		Perennial crop	Perennial crop	
		Open/Barren	Open/Barren	
4	-	Inland water	Inland water	Water
5	Grassland	Grassland	Grassland	Grassland
	Wooded grassland	Wooded grassland		

Table 6. Summary of the change detection analysis for 2005 to 2010.

Pixel value	New class	Reference class	No. of pixels	Area (ha)
2	1	2	8	0.72
8	1	5	7308	657.72
3	2	1	1679	151.11
5	3	1	10844	975.96
7	4	1	3176	285.84
10	5	1	80815	7273.35

Table 7. Summary of the change detection analysis for 2010 to 2015.

Pixel value	New class	Reference class	No. of pixels	Area (ha)
2	1	2	324	29.16
4	1	3	3621	325.89
7	1	4	1200	108
11	1	5	66821	6013.89
3	2	1	700	63
6	3	1	6590	593.1
10	4	1	926	83.34
15	5	1	4200	378

Table 8. Summary of the change detection analysis for 2015 to 2020.

Pixel value	New class	Reference class	No. of pixels	Area (ha)
1	-999	1	4311	387.99
7	1	2	1808	162.72
9	1	3	16993	1529.37
12	1	4	503	45.27
16	1	5	12615	1135.35
8	2	1	3561	320.49
11	3	1	7707	693.63
15	4	1	1609	144.81
20	5	1	36319	3268.71

found that existing roads contribute to forest conversion. Moreover, the findings of the study have resulted in the same analysis as the study of Milien *et al.* (2021) about roads, deforestation, and the mitigating effect of the Chico Mendes Extractive Reserve in the southwestern Amazon, where it was found that deforestation is also known to be caused by roads. Nepstad *et al.* (2001), Southworth *et al.* (2011), and Barber *et al.* (2014) have all found that deforestation is concentrated in road corridors in the Amazon.

Furthermore, the UMW Coalition has reported that the UMW was being exploited by extractive activities such as quarrying and mining in the area. According to the coalition, at least six Mineral Production Sharing Agreements (MPSAs) exist or overlap with the UMRBPL, covering approximately 1,500 ha of protected forestland. Another 658 ha appear to be covered by MPSAs in nearby protected and conserved areas. The existence of mining and quarrying sites calls for the existence of road networks for transportation. These MPAs greatly contribute to the increasing presence of road network developments and the decrease of forest cover over time.

The UMW was put into the UMRBPL status in November 2011. The initial efforts of this mandate have contributed to strengthening the protection of the watershed resulting in fewer extractive activities in the area that have caused a forest cover increase in this period. From 2010 to 2015, an increase in forest cover was recorded on the site (**Figure 11**).

Even though the UMW was put into a protected landscape status, the data above for 2015 to 2020 shows that a decrease in forest cover is still happening in the area. Many small but numerous

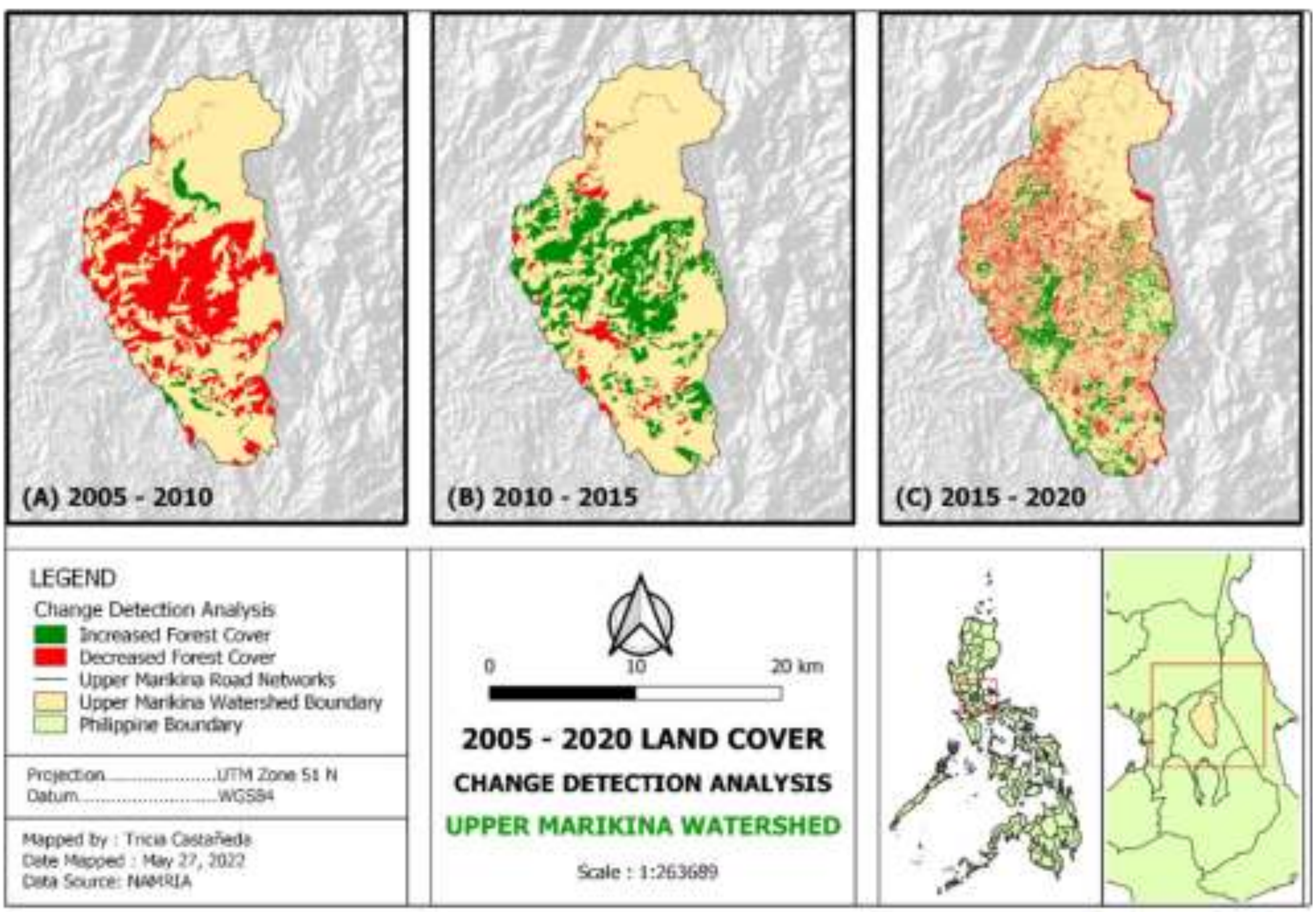


Figure 10. Change of forest cover in Upper Marikina Watershed from 2005 to 2020 (right).

watershed regions have shown a 17.23% forest cover decrease from 2015 to 2020, along with a 10.28% forest cover increase. The protected landscape status change from a reserve, as defined by R.A. 7586, is a lenient move involving man in nature compared to a reserve. This protected landscape status may have opened opportunities for road network establishments as transportation in this area is a need if human exists and thrives in the area. Moreover, the study by Poor *et al.* (2019) found that the improved forest access along the forest boundary is due to roads that are a major driver of deforestation and degradation. It was discussed in this study that protected areas worldwide must address roads and their consequences on ecosystem fragmentation in their conservation plans.

Overall, **Figure 11** shows that the area's road networks show an inverse relationship with the forest cover in the UMW. Data from 2005 to 2020 show that forest cover decreases as road network development increases. With the increase or massive growth of road networks in the area, the forest cover showed a noticeable change over time. As road networks develop through time, changes in forest cover in the UMW occur. The period from 2010 to 2015 shows an increase in forest cover, and it can be concluded that putting the UMW into a protected landscape status effectively contributed to this increase. Generally, the graph and the table showed an inverse relationship between the road network and forest cover in UMW. When the road network was developed increasingly in the area, the forest cover decreased.

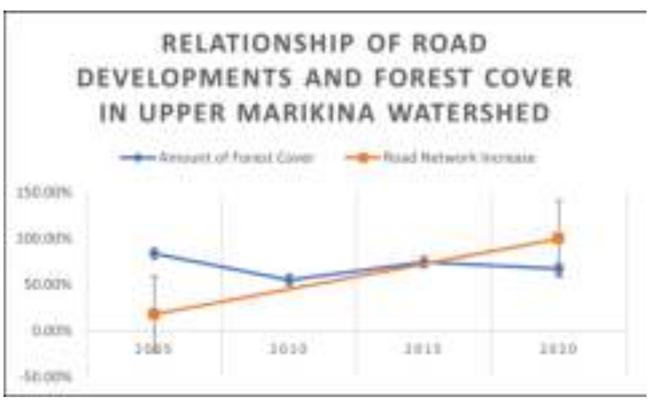


Figure 11. Line graph showing the relationship between road network developments and forest cover in Upper Marikina Watershed.

CONCLUSION AND RECOMMENDATIONS

Destructive activities, unregulated exploitation, and excessive land conversion have threatened UMW. Analysis showed that the forest cover of the UMW has changed over time. From 2005 to 2010, a significant decrease in forest cover was recorded, while a noticeable increase occurred between 2010 and 2015. However, as years go by, a continuous decrease in forest cover occurred from 2015 to 2020 based on the results and analysis of this study. All these changes in forest cover due to further land conversion in the area create opportunities for road network developments. Furthermore, the lack of tenure security, coupled with the perception of open access to the forest as a shared resource, has negatively impacted forest cover due to road network development in the UMW.

The findings revealed significant changes in forest cover in the UMW between 2005 and 2020. Specifically, the expansion of the road network in the area inversely correlates with forest cover. This study can contribute to improved land use planning, strengthened policy enforcement, and policy formulation in land resource planning, monitoring, and management.

For future studies, field verification of the land cover and road network extent in the area would be useful in enhancing the accuracy of the data. Also, a study using satellite images taken in various years and more specific land cover classification could better assess land cover change in the area.

ACKNOWLEDGMENT

Sincerest thanks to NAMRIA, DENR, and DOST for all the assistance that led to the completion of the study.

LITERATURE CITED

Abino, A. C. Sung, Y. K., Mi, N. J, Young, J. L., & Joo, S. C. (2015). Assessing land use and land cover of the Marikina sub-watershed, Philippines, *Forest Science and Technology*, *11*(2), 65–75.

Barber, C., Cochrane, M. A., Souza Jr., C. M., Laurance, W. F. (2014). Roads, deforestation, and the mitigating effect of protected areas in the Amazon. *Biological Conservation*, pp. 1, 203–20.

Clements, G. (2013). *The Environmental and Social Impacts of Roads in Southeast Asia*. James Cook University. Retrieved from: <https://researchonline.jcu.edu.au/31888/1/31888_Clements_2013_thesis.pdf>.

David, C., & Pellejera N. (2011). Reconstructing the Tropical Storm Ketsana flood event in Marikina River, Philippines. *Hydrology and Earth System Sciences*, *15*(4), 1283.

DENR [Department of Environment and Natural Resources. (2017). Guidelines on the Implementation of Sustainable Integrated Area Development (SIAD) Strategy. DENR Administrative Order 2017-02. Retrieved from: <https://www.informea.org/sites/default/files/legislation/DENR%20Administrative%20Order%202%202017%20%28Guidelines%20on%20Implementation%20of%20Sustainable%20Integrated%20Area%20Development%20%28SIAD%29%20Strategy%29.pdf>.

DENR [Department of Environment and Natural Resources. (2015) Sub-Sectoral Assessment DENR. Retrieved from: <https://forestry.denr.gov.ph/pdf/mp/9.%202.00%20Sub-sectoral%20Assessment.pdf>.

ESRI. (2021). Accuracy Assessment for Image Classification. ArcGIS. ESRI. Retrieved from: <https://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/accuracy-assessment-for-image-classification.htm#:~:text=Accuracy%20assessment%20is%20an%20important,is%20time%20consuming%20and%20expensive>.

Forman, R. T., & Alexander, L. E. (1998). Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29, 207–231.

Kastridis, A. (2020). Impact of Forest Roads on Hydrological Processes. *Forests*, *11*(11), 1201. doi:10.3390/f11111201

Laurance, W. F., Campbell, M. J., Alamgir, M., & Mahmoud, M. I. (2017). Road Expansion and the Fate of Africa's Tropical Forests. *Frontiers in Ecology and Evolution*, 5. doi:10.3389/fevo.2017.00075

Leonard, R. J., & Hochuli, D. F. (2017). Exhausting all avenues: Why impacts of air pollution should be part of road ecology. *Frontiers in Ecology and the Environment*, *15*(8), 443–449.

Milien, E. J., Rocha, K. S., Brown, I. F., & Perz, S.G. (2021). Roads, deforestation, and the mitigating effect of the Chico Mendes extractive reserve in the southwestern Amazon, Trees, Forests, and People. Volume 3. 100056. ISSN 2666-7193. https://doi.org/10.1016/j.tfp.2020.100056.

NRC [National Research Council]. (1993). *Population and Land Use in Developing Countries: Report of a Workshop*. Washington, DC: The National Academies Press. DOI: 10.17226/2211

Nepstad, D. C., Carvalho, G., Barros, A. C., Alencar, A., Capobianco, J. P., Bishop, J., Moutinho, P. R., Lefebvre, P. A., Silva, U. L., & Prins, E. (2001). Road paving, fire regime feedbacks, and the future of Amazon forests. *Forest Ecology and Management*, *154*, 395–407.

Olchondra, R. (2012). Release of Marikina Watershed Fund Sought. Retrieved from: <http://business.inquirer.net/39355/release-of-marikina-watershed-fund-sought>.

Paragas, V., Manzano, J., & Cacanindin, D. (n.d.) Land Use Planning Strategies on Watershed Management and Disaster Reduction in the Philippines. Retrieved from: <http://wgbis.ces.iisc.ernet.in/energy/HC270799/LM/SUSLUP/Thema4/255/255.PDF>.

Philippines Forestry Statistics. (2020). Forest Management Bureau, DENR. Retrieved from: <https://forestry.denr.gov.ph/index.php/statistics/philippines-forestry-statistics>.

Poor, E. E., Jati, V. I. M., Imron, M. A., & Kelly, M. J. (2019). The road to deforestation: Edge effects in an endemic ecosystem in Sumatra, Indonesia. *PLOS ONE*, *14*(7), e0217540. doi:10.1371/journal.pone.0217540

Southworth, J., Marsik, M., Qiu, Y., Perz, S., Cumming, G., Stevens, F., Rocha, K., Duchelle, A., & Barnes, G. (2011). Roads as drivers of change: Trajectories across the tri-national frontier in MAP, the southwestern Amazon. *Remote Sensing*, *3*, 1047–1066.

Yan, G. (2020). A 'Game of Trees.' Department of Environment and Natural Resources – Foreign-Assisted and Special Projects Service. Retrieved from: <http://fasps.denr.gov.ph/index.php/resources/news-and-information/biodiversity/23-a-game-of-trees>.

p-ISSN 2012-3612 │ e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 │ Number 1 │ pp. 47–57│ 2023

Suitability assessment of Kalantas (*Toona calantas* Merr. & Rolfe) and Supa (*Sindora supa* Merr.) in the Quezon Protected Landscape using weighted overlay analysis

Giorjia Mae L. Veran[1]*, Romnick S. Baliton[1], Marco A. Galang[1]

[1] *Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. One of the most cited reasons behind the failure of reforestation activities in the country is the lack of species-site matching, especially for Philippine native tree species. This, among other reasons, resulted in the extensive use of exotics for local forest rehabilitation activities, which may pose a serious threat to the country's native biodiversity if not appropriately addressed. This study provides future reforestation programs with information regarding the suitable areas for two threatened native tree species, namely Kalantas (*Toona calantas* Merr. & Rolfe) and Supa (*Sindora supa* Merr.), within the Quezon Protected Landscape (QPL). Brush/shrub lands, grasslands, and open forests within the QPL were identified as potential reforestation sites. The silvical requirements of the species from secondary sources were matched with the characteristics of the identified reforestation sites using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) indices developed by Dolores *et al.* (2020). The study revealed that both *T. calantas* and *S. supa* are highly suitable for all the identified potential reforestation sites within the QPL. The identified potential reforestation sites cover 864 ha (8.64 km^2) or approximately 92% of the landscape. Therefore, the present study's findings are useful for future reforestation programs in the QPL and the utilization of *T. calantas* and *S. supa* for such forestation initiatives.

Keywords: Integrated analytic hierarchy process, reforestation, species-site matching

Article Information
Received 20 September 2022
Accepted 26 May 2023
Published online 16 October 2023
*Email: glveran@up.edu.ph

INTRODUCTION

The Quezon Protected Landscape (QPL), traversing the municipalities of Atimonan, Pagbilao, and Padre Burgos in Quezon Province, is recognized as a biologically important zone by virtue of Proclamation No. 394 following the National Integrated Protected Areas Systems (NIPAS) Act of 1992. Although under the protection and management of the Department of Environment and Natural Resources-Protected Area Management Board (DENR-PAMB), QPL is not completely safeguarded from anthropogenic threats. A significant portion of the landscape serves rural residential purposes, making these areas and the entire landscape vulnerable to invasive human activities (Conda & Buot, 2016; Villanueva & Buot, 2017; Paclibar & Tadiosa, 2020). One threat worth noting is the presence and patronage of invasive alien plant species (IAPS). Therefore, any effort to restore and reforest the degraded segments of the QPL must carefully consider the species selection, primarily the use of suitable native species, thus, this research.

Both species are native to the Philippines and are classified as threatened by either or both the International Union for Conservation of Nature (IUCN 2021-3) and the Philippine National Red List (DENR DAO 2017-11). *Toona calantas* Merr. & Rolfe is yet to be assessed by the IUCN as it is presently under the "Data Deficient" category (Barstow, 2018). However, it was once locally deemed as Critically Endangered (DENR DAO 2007-01) before its current classification as a "Vulnerable" species (DENR DAO 2017-11). On the other hand, the IUCN classifies *Sindora supa* Merr. as a Vulnerable species, while the same species were categorized in the Philippine National Red List as endangered (EDC, 2020a; EDC, 2020b). In this light, propagating and conserving these two species within their native and suitable habitats is important. Interestingly, previous studies have documented the natural occurrence of *T. calantas* in the QPL (Tadiosa *et al.*, 2016; Paclibar & Tadiosa, 2020). Although no recent studies have yet accounted for the existence of *S. supa* in the QPL, it was found as a dominant species in another karst formation in the country located in Palawan (Tolentino *et al.*, 2020). Hence, the karst forest of the QPL can potentially be a suitable site for *S. supa*. Moreover, the common names of the species, including supa, pania, and parina, are widely attributed to the vernaculars of the Quezon province (ERDB, 2018).

Geographic Information System, or GIS, is a contemporary method of visualizing geospatial data. With this technology, physiographic features can be organized into a map that, in this case, matches the site characteristics with the silvical requirements of the selected species. Like GIS, the AHP is a tool that aids decision-making. AHP is more widely applied in multi-criteria decision-making situations wherein the relative strength of each criterion against the others in a system is reflected in ratio scales (Saaty, 1987). Although species-site matching is inherently a multi-criteria decision-making process, AHP had only been formally used in this discipline by Dolores *et al.* (2020) as they evaluated the suitability of *Albizia acle* (Blanco) Merr., *Alstonia scholaris* (L.) R. Br., and *Agathis philippinensis* (Warb.) to the Pantabangan-Carranglan Watershed in Luzon. In that same study, the authors were able to establish, albeit only fundamentally, the reliability of the use of GIS and AHP in future species-site suitability assessments, like this present study.

Despite being done ever since the early 1900s, most reforestation programs in the country had always been described as "of little success, or worse as "failed" endeavors (Lasco *et al.*, 2006; Tolentino, 2008; Le *et al.*, 2013; Schneider *et al.*, 2014). The same authors recognize the need for more species-site matching studies and using indigenous tree species in its suitable grounds as one of the promising ways forward for both forest rehabilitation and plantations. This research follows such recommendations and consequently aims to assess the suitability of *T. calantas* and *S. supa* to the degraded and potential reforestation sites within the QPL using GIS and AHP indices. Before the suitability assessment, the authors identified the degraded areas within the QPL and determined the silvical requirements of the selected native species using secondary sources.

METHODOLOGY

Description of the study site

The QPL, formerly known as Quezon National Park, covers approximately 938 ha of land. It traverses three municipalities of Quezon Province, namely, Atimonan (Brgy. Santa Catalina and Brgy. Malinao Ilaya) in the northeastern side, Padre Burgos (Brgy. Sipa) in the southeastern portion, and Pagbilao (Brgy. Silangan Malicboy) in the western region of the landscape (**Figure 1**). It is located between 13^{0}58′00′′ and 14^{0}01′00′′ latitudes and between 121^{0}47′00′′ and 121^{0}50′00′′ longitudes around 160 km southeast of the City of Manila. QPL is considered a part of the Sierra Madre Mountain range, with its highest elevation of 380.4 m asl and its lowest point of 12.5 m asl (**Figure 2**).

The site has a Type II Climate, characterized by the absence of a dry period but with a pronounced wet season from November to February. Based on the data of PAGASA from 2009 to 2019, the mean annual temperature in the entire QPL ranges from 26.9^{0}C to 27.1^{0}C, while the area received an

Figure 1. Location map of the Quezon Protected Landscape.

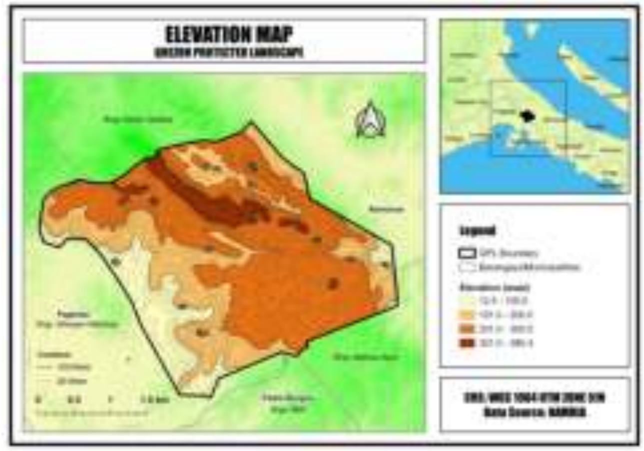


Figure 2. Elevation map of the Quezon Protected Landscape.

average annual rainfall of 3,027 to 3,043 mm. The soil of the entire landscape belongs to the soil series known as Bantay clay. According to Carating *et al.* (2014), Bantay soils have limestone origins and are usually cultivated if not covered with grasses or secondary growth forests. The soil textural class of the Bantay clay ranges from clay-to-clay loam with a pH ranging from 5.5 to 7.5 (Descalsota *et al.*, 2005; Carating *et al.*, 2014).

Species selection

Both species selected for this study are threatened Philippine natives (**Table 1**). *Sindora supa* is even an endemic species of the Philippines. *Toona calantas* was selected for the study because recent studies reveal its natural occurrence in the site (Tadiosa *et al.*, 2016; Paclibar & Tadiosa, 2020). While *S. supa* was recently found to be a dominant species in a karst forest of Palawan, it has not been found existing in the QPL, whose karst formations are located around the popular Pinagbanderahan Peak with elevation ranging from 249 to 342 m asl (Paclibar & Tadiosa, 2020; Tolentino *et al.*, 2020). Several common names of the *S. supa*, including supa, pania, and parina, are also attributed to the vernaculars of Quezon Province (ERDB, 2018). Due to these, the present study explored the potential of the QPL as a suitable site for *S. supa*.

The silvical requirements of the selected species were gathered through secondary data gathering such as but not limited to published articles, theses, and online databases. All sources consulted in determining the requirements of the selected species are enumerated in **Table 2**.

The temperature and rainfall requirement of the species were derived from publicly available climate information of PAGASA and climatedata.org. The average annual rainfall and average annual temperature of the sites where the species naturally occur, as reported by the ERBD (2014, 2018) and Quisumbing (1978), was regarded as the actual range required for the growth and survival of the species.

According to the Bureau of Soils and Water Management (BSWM) soil map and Carating *et al.* (2014) descriptions, the soil textural class in the species' natural distribution areas was considered the species' preference. All soil pH values of the identified soil profiles required by the two (2) species were then derived from the study of Descalsota *et al.* (2005). Since the study of Fernandez (2015) revealed that *S. supa* grew better in Makiling soil with a soil textural class under the silty clay classification and pH of 7.14, it was used as an additional basis for the reported soil textural class and soil pH preference of *S. supa*.

Since the ERDB only reported "low to medium" elevations as the site requirements of the species, other studies were sought for the preferred elevation ranges. The elevation features of St. Paul's Bay in Palawan, where *S. supa* was reported as a dominant species, and that of Sitio Dicasalarin

Table 1. Conservation status of the selected native species based on the Philippine National Red List (DAO 2017-11) and the International Union for Conservation of Nature (IUCN 2021-3).

Selected native species	DAO 2017-11	IUCN 2021-03
Toona calantas	Vulnerable	Data deficient
Sindora supa	Endangered	Vulnerable

Table 2. Secondary sources consulted to determine the site requirements of Kalantas (*Toona calantas*) and supa (*Sindora supa*).

Site feature	*Toona calantas*	*Sindora supa*
Average annual rainfall (mm yr-1)	ERDB PAGASA climatedata.org	ERDB PAGASA climatedata.org Fernando *et al.* (2008)
Soil textural class	BSWM	BSWM Fernandez (2015) Coracero & Malabrigo (2020)
Soil pH	BSWM Descalsota *et al.* (2005)	BSWM Fernandez (2015) Coracero & Malabrigo (2020) Descalsota *et al.* (2005)
Elevation (m asl)	ERDB Lapitan *et al.* (2015)	ERDB Coracero & Malabrigo (2020) Fernando *et al.* (2008)
Average annual temperature (^{o}C)	ERDB Fernando *et al.* (2008	ERDB Fernando *et al.* (2008)

in Brgy. Zabali, Baler, Aurora were ranked 21st out of the 139 surveyed species in terms of carbon stock were considered. On the other hand, the elevation requirement of the *T. calantas* was also derived from the study of Lapitan *et al.* (2015), which assessed the spatial distribution of the species within the Mt. Makiling Forest Reserve (MMFR).

Thematic mapping of site characteristics

Using QGIS (version 3.16), an open-source GIS software developed by the Open Source Geospatial Foundation (OSGeo), thematic maps of the site characteristics (elevation, rainfall, temperature, soil textural class, and soil pH) were generated. The sources of all data used for this study are enumerated in **Table 3**.

Determination of potential reforestation sites

The land cover map from the National Mapping and Resource Information Authority (NAMRIA) determined the degraded areas within the QPL. The map shows the extent of forests, agricultural lands, built-up areas, and brush/shrub lands (**Figure 3**). As per the mandate of the Republic Act No. 7586 or the National Integrated Protected Areas Systems (NIPAS) Act of 1992, protected areas like the QPL are set aside and managed for ecosystem protection and development. Hence, areas within the QPL that are no longer densely forested, *i.e.*, brush/shrublands and open forests, were identified as degraded sites.

Figure 3. Land cover map of the Quezon Protected Landscape.

Table 3. Summary of data sources used for the thematic maps of the Quezon Protected Landscape.

Data	Source	Description
Elevation	NAMRIA	Interferometric Synthetic Aperture Radar (IfSAR)-Digital Terrain Model (DTM) at 5-meter by 5-m resolution in raster format
Mean annual precipitation	ClimDatPh (DOST-PAGASA)	2009-2019 Annual rainfall (mm) data in CSV file format
Mean annual temperature	ClimDatPh (DOST-PAGASA)	2009-2019 Annual average temperature (^{0}C) data in CSV file format
Soil textural class and pH	Department of Agriculture-BSWM	Soil textural classes in shapefile forma
Land cover	NAMRIA	2020 Philippine land cover in shapefile forma

Factor suitability scoring

The different site factor values, *viz.*, number of meters above sea level (m asl) for the elevation, millimeters (mm) of mean annual rainfall, degrees in Celsius (^{0}C) for the mean annual temperature, soil textural type, and soil pH, were reclassified into suitability scores. The site factors included in this analysis were those used by Dolores *et al.* (2020), whose developed AHP weights were adopted for the present study. Suitability scores vary from 1 to 3, where 1 denotes marginal suitability, 2 is moderate, and 3 means high suitability. Reclassification is based on the requirement or preference of the species – the closer the site factor is to the species requirement, the higher the potential suitability of the species to the site. The requirement or preference of the species is the range of site characteristics wherein the species naturally grows. Such was derived from its natural distribution range and/or experimentation results; whichever literature is available. For illustration (**Figure 4**), species preferences may be viewed as the "target" site characteristics. Hence, the suitability score is considered 1 or high if the site falls within this range. Similar site characteristics, such as a similar but not exact soil textural class, are considered moderate suitability. Otherwise, the site is only of marginal suitability. This reclassification scheme for the different site factors is also defined in **Table 4**. The suitability scores of each site factor per species obtained will be multiplied by the weights acquired using AHP.

Species-site matching

The entire process followed the approach developed by the Food and Agriculture Organization (FAO, 1982) for the physical evaluation of forestry land potential. In this regard, the formula for the suitability index shown in **Equation 1** was used to assess the suitability of the identified potential reforestation areas in the QPL for the selected forest species.

Equation 1.

$$S = \sum W_i X_i$$

Where: S = suitability index, i = each site factor,
W = weight of each i, X = score of each class i.

The different site factors investigated in this study are the same site factors utilized by Dolores *et al.* (2020) using AHP. In lieu of this, the weights of the different site factors (W) used in obtaining the suitability index are hereby adopted from the site factor weight determination done by Dolores *et al.* (2020). The AHP weights developed in the study of Dolores *et al.* (2020) are summarized in **Table 5**.

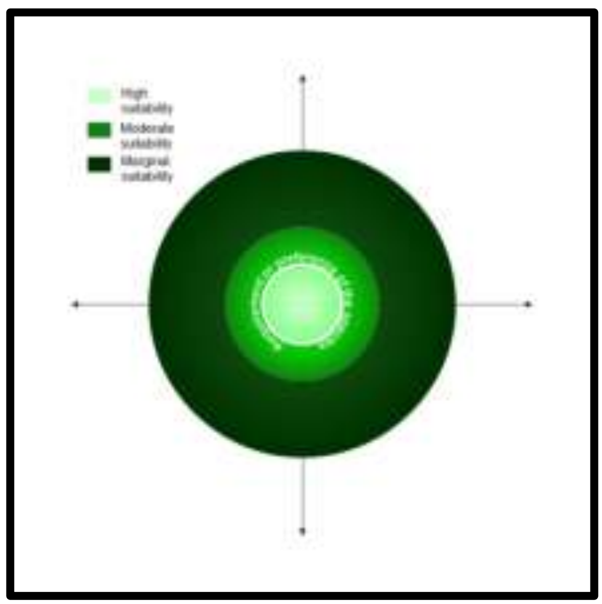


Figure 4. Scheme of reclassification of site factors into suitability scores.

Table 4. Reclassification of the di ferent site factor values into suitability scores.

Site factor	Suitability score		
	Marginal (1)	Moderate (2)	High (3)
Elevation	Areas outside the elevation requirement of the species.	Areas not within the elevation requirement but with a similar elevation range.	Areas that fall within the required elevation range of the species.
Mean annual rainfall	Areas receiving less or more than the mean annual rainfall required by the species.	Areas receiving a similar amount of mean annual rainfall to that the species requires.	Areas receiving an annual rainfall within the amount preferred by the species.
Mean annual temperature	Areas with a mean annual temperature that is beyond the temperature requirement of the species.	Areas with a mean annual temperature that is not within but similar to the temperature requirement of the species.	Areas with mean annual temperatures are within the range required by the species.
Soil textural class	Areas without the same nor similar soil textural class requirement of the species.	Areas without the same soil textural class but with soil that belongs to a similar soil textural class to that required by the species.	Areas with the same soil textural class as that required by the species.
Soil pH	Areas with soil pH that is beyond that required by the species.	Areas with soil pH that is not within the range required by the species but has a similar pH.	Areas with soil pH that has or is within the species requirement.

Table 5. Site factor weights developed by Dolores *et al.* (2020) using the Analytic Hierarchy Process.

Site factor	Weight (%)
Mean annual rainfall	24.5
Soil textural class	23.04
Soil pH	22.48
Elevation	19.27
Mean annual temperature	10.71

Secondary data collected were used to reclassify the site factors' suitability values. The 2020 Land Cover data from NAMRIA was used to identify the potential reforestation sites within the QPL. The characteristics of the identified potential reforestation areas in the QPL and the species requirements were reclassified into suitability scores in **Tables 7** and **8** for *T. calantas* and *S. supa*, respectively.

Raster analysis in QGIS was done for every site factor to determine the extent of suitable areas within the identified potential reforestation sites in QPL. After this, the AHP weights Dolores *et al.* (2020) developed were applied to the obtained suitability scores. The obtained suitability indices, *i.e.*, the summation of the products of the site factor weights and their suitability scores, were again reclassified into marginal (≤ 1.00), moderate (1.01 - 2.00), and high (≤ 2.01). The raster analysis mainly included using the following tools: reclassify by table and raster calculator. All the weighted site factor maps for each selected species were integrated using the analysis above and tools in QGIS (version 3.16), and the overall extent of suitability in hectares was determined for each species.

RESULTS AND DISCUSSION

Potential reforestation sites in the Quezon Protected Landscape

Areas within the QPL that are no longer densely forested were identified as degraded sites. Since the forests in the land cover map have no closed canopies, areas with open forests were identified as potential reforestation sites with brush/shrub lands (**Figure 5**). The assumption is that these areas will need some reforestation in the future.

Table 6. Site characteristics of the Quezon Protected Landscape, site requirements of T*oona calantas*, and the reclassified suitability scores for each site factor.

Site factor	Quezon Protected Landscape	*Toona calantas*	Score
Average annual rainfall (mm yr-1)	3,027 - 3,043	950 - 4,100	3
Soil textural class	Clay - Clay loam	Loam	2
Soil pH	5.5 - 7.5	5.0 - 6.7	2
Elevation (m asl)	12.5 - 380.4	100 - 500	2 for 0-100 3 for 100-500
Average annual temperature (^{0}C)	26.9 - 27.1	25 - 30	3

Table 7. Site characteristics of the Quezon Protected Landscape, site requirements of *Sindora supa*, and the reclassified suitability scores for each site factor.

Site factor	Quezon Protected Landscape	*Sindora supa*	Score
Average annual rainfall (mm yr-1)	3,027 - 3,043	1,500 - 3,500	3
Soil textural class	Clay - Clay loam	Silty clay - Clay loam	3
Soil pH	5.5 - 7.5	6.0 - 7.3	2
Elevation (m asl)	12.5 - 380.4	300 - 1,000	2 for 0-300 3 for >300
Average annual temperature (^{0}C)	26.9 - 27.1	25 – 30	3

Silvical requirements of the selected species

Various publications and databases were sought to complete the silvical requirements of *T. calantas* and *S. supa* because primary experimentation nor data collection could not be done in this study. The silvical or site requirements of the species usually include a range of characteristics summarized per site factor in **Table 8**.

Suitability of the selected species

Tables 6 and **7** present the suitability scores assigned for every site factor for *T. calantas* and *S. supa*, respectively. The site factors were presented according to their respective AHP weights (**Table 5**). The suitability scores were based on the reclassification criteria – wherein areas outside the species requirement are marginally suitable (score = 1), areas with similar features to that preferred by the species were moderately suitable (score = 2), and ultimately, the sites with characteristics that are the same or within the species requirement are highly suitable areas (score = 3).

All the identified potential reforestation sites within the QPL were highly suitable for both *T. calantas* and *S. supa*. **Figures 6** and **7** show that no marginal nor moderately suitable areas were found for both species and that 858.13 ha, or 100% of the identified potential reforestation sites, are highly suitable for *T. calantas* and *S. supa*.

Toona calantas obtained an overall suitability index ranging from 2.35 to 2.54 across potential reforestation sites. This index falls under the high suitability class. *S. supa*, on the other hand, g arnered a suitability index of 2.58 to 2.78 – an index also classified under the high suitability class. The QPL is a relatively small and uniform site with little considerable variations in soil, climate, and elevation. Results further shows that the requirements of the species are well-fitted in the characteristics of the QPL as the suitability scores ranged from 2 (moderate) or 3 (high).

Table 8. Site requirements of Kalantas (*Toona calantas*) and supa (*Sindora supa*).

Site feature	*Toona calantas*	*Sindora supa*
Average annual rainfall (mm yr-1)	950 - 4,100	1,500 - 3,500
Soil textural class	Loam	Silty clay - Clay loam
Soil pH	5.0 - 6.7	6.0 - 7.3
Elevation (m asl)	100 - 500	300 - 1,000
Average annual temperature (°C)	25 - 30	25 - 30

The results of this study are outliers when viewed side by side with previously conducted species-site suitability assessments in the country. No recent studies for various local sites and species have obtained 100% high suitability. None has obtained even 100% low nor 100% moderate suitability results. To cite, only one of the three selected species examined by Dolores *et al.* (2020) obtained high suitability for the Pantabangan-Carranglan Watershed (PCW). This high suitability was observed for 53% of the identified potential reforestation sites. Sarmiento & Casas (2015) found no highly suitable areas for their selected species in the Mt. Mayapay Watershed of Butuan City, Agusan del Norte. Lastly, Galang (2010) found that only a small percentage of the MMFR is highly suitable for narra.

Nonetheless, the previous literature is consistent with the findings of this study and vice versa. None of the previously evaluated sites were as small and relatively uniform as the QPL. The QPL only has 983 ha or 9.83 km^2 of area, while the PCW is more than 133,000. Mt. Mayapay Watershed is more than 18,000 ha, while the MMFR exceeds 4,000 ha. All the previously examined sites are many times bigger than the QPL. Following Tobler's First Law of Geography, the variation of site characteristics increases as the area of the site increases. Therefore, larger sites would have more sources of variation in terms of site factors. Consequently, larger sites would yield more varied suitability results like other studies' findings.

Another way to confirm variations in the site characteristics is through primary data collection, especially for the soil characteristics which textural class and pH have a weight of 23.04% and 22.48%, respectively. Soil textural class ranked second, while soil pH ranked third in the adopted AHP weights developed by Dolores *et al.* (2020). Unfortunately, the present study could not conduct primary data collection nor any actual experimentation due to constraints brought about by the pandemic.

It is important to note, however, that despite being valid, the findings of this study do not ensure 100% survival of the species to the QPL, nor will it ensure 100% success of reforestation programs in the QPL if *T. calantas* and *S. supa* are used. Apart from the site characteristics, there remain to be other factors that affect the survival of the species, such as the quality of the germplasm used, silvicultural practices, and the presence of pests or pathogens, among others (Tolentino, 2008; Schneider, 2014). Proper species-site matching is likewise only one component or a single driver among many other drivers that facilitate the success of forest rehabilitation endeavors in the Philippines (Le *et al.*, 2013). Other components of the technical/biophysical driver identified by Le *et al.* (2013) were site preparation, planting activity timing, technical capacity, and silviculture. Species-site suitability assessments cannot solely address these other components. Other reforestation success drivers are enabling socio-economic, institutional, political, and management conditions.

CONCLUSIONS AND RECOMMENDATIONS

The study determined that there are around 864 ha of potential reforestation sites within the QPL. This is around 92% of the entire site and comprises areas with open forests and brush/shrublands, according to the 2020 Land Cover Map of NAMRIA. Most importantly, both species

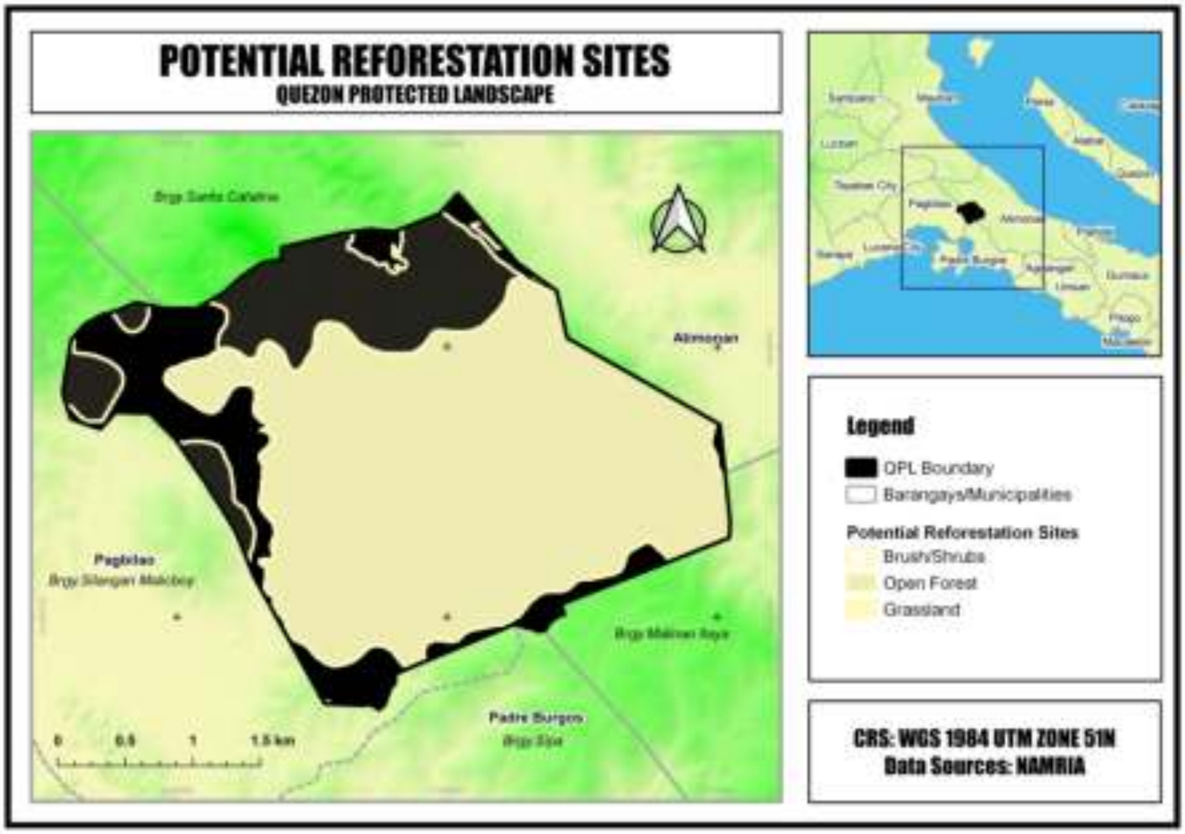


Figure 5. Land cover map of the potential reforestation sites in Quezon Protected Landscape.

are highly suitable in all the identified potential reforestation sites. The site requirements of *T. calantas* and *S. supa* were found to highly match the site characteristics of the QPL.

Toona calantas and *Sindora supa* were highly suitable for all the identified potential reforestation sites within the QPL. The site uniformity can explain the small variation in the suitability results obtained. QPL also belongs to a single soil series with minimal variations in climate and elevation. Belonging to a single soil series meant having the same soil textural class and soil pH – site factors that rank second and third in AHP weights.

While the study provided practical information on the utilization of *S. supa* and *T. calantas*, it remains limited by the availability and quality of secondary sources used. Field validation to verify the site characteristics and requirements remain important activities to execute. Primary data collection and analysis, especially of the soil characteristics and site lithology, are crucial because the characteristics of this site factor, namely, textural class and pH, all together weigh 45.52%. Not only do soil characteristics have a considerably large weight, but the variations in the soil characteristics are also high. Therefore, it is suggested that primary soil analysis must be done and future research must consider selecting different species mixes and/or other critical and key biodiversity sites.

ACKNOWLEDGMENTS

This study was made possible by the valuable contributions of the following institutions: financial support from the Department of Science and Technology-Science Education Institute (DOST-SEI) and data inputs from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), National Mapping and Resource Information Authority (NAMRIA), Bureau of Soils and Water Management (BSWM), and Ecosystems Research and Development Bureau (ERDB).

Figure 6. Suitability map of Kalantas to the identified potential reforestation sites with the Quezon Protected Landscape.

Figure 7. Suitability map of Supa to the identified potential reforestation sites with the Quezon Protected Landscape

LITERATURE CITED

Barstow, M. (2018). Toona calantas. The IUCN Red List of Threatened Species 2018: e.T32122A68105077. Retrieved on April 24, 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2018-1.RLTS.T32122A68105077.en>.

Carating, R. B., Galanta, R. G., & Bacatio, C. D. (2014). The soils of the uplands. *In: The Soils of the Philippines. World Soils Book Series*. Springer, Dordrecht. DOI: 10.1007/978-94-017-8682-9_3. pp. 107–147.

Conda, J. M. & Buot, I. E. Jr. (2016). Biodiversity assessment and conservation status of some pteridophytes in the northeastern portion of Quezon Protected Landscape, Philippines. *The Thailand Natural History Museum Journal, 10*(1), 15–31.

Coracero, E. E. & Malabrigo, P. (2020). Carbon storage potential of the tree species along the ultramafic forest in Sitio Dicasalarin, Barangay Zabali, Baler, Aurora, Philippines. *AIMS Environmental Science, 7*(6), 589–601.

Descalsota, J. P., Mamaril, C. P., & San Valentin, J. O. (2005). Fertility status of selected rice soils in the Philippines. *Philippine Journal of Crop Science, 28*, 45–57.

Dolores, J. C. R., Galang, M. A., & Dida, J. J. V. (2020). Species-site suitability assessment of native species in Pantabangan-Carranglan watershed using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP). *Philippine Journal of Science, 149*(3), 529–537.

EDC [Energy Development Corporation]. (2020). *Sindora supa*. The IUCN Red List of Threatened Species 2020: e.T32809A67803839. Retrieved on 24 April 2021, from <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T32809A67803839.en>.

ERDB [Ecosystems Research and Development Bureau]. (2014). Compilation of selected forest species from Vol. 2 No. 1-12, 1990. Ecosystems Research and Development Bureau. *Research Information Series on Ecosystems (RISE), 26*(1–2), 50–59.

ERDB [Ecosystems Research and Development Bureau]. (2018). Threatened Philippine forest tree species: Kamatog (*Sympetalandra densiflora* (Elm.) Steenis) and Supa (*Sindora supa* Merr.). Ecosystems Research and Development Bureau. *Research Information Series on Ecosystems (RISE), 30*(3).

Fernandez, R. A. M. F. (2015). Effects of EM-1 Application on the growth of Supa (*Sindora supa* (Merr.)) seedlings planted in Caliraya (Luisiana Clay Loam) and Makiling (Macolod Clay Loam) soils [Thesis Manuscript]. College, Laguna: UPLB-CFNR.

Fernando, E. S., Suh, M. N., Lee, J., & Lee, D. K. (2008). Forest formation of the Philippines. ASEAN-Korea Environmental Cooperation Unit, Seoul National University, Seoul, Republic of Korea. 232 p.

Galang, M. A. (2010). GIS-Aided suitability assessment of Mt. Makiling Forest Reserve (MFR), Philippines for smooth Narra (*Pterocarpus indicus* Willd.). University of Southern Mindanao *Research and Development Journal, 18*(1), 67–72.

Lapitan, P., Castillo, L., Balatibat, J., Castillo, M., & Bantayan, N. (2015). Spatial distribution of Kalantas (*Toona calantas* Merr. & Rolfe) in the Molawin –Dampalit Watershed, Mount Makiling Forest Reserve, Philippines. *Ecosystems & Development Journal*, *5*(3), 33–42.

Lasco, R. D., Carandang, A. P., Chokkalingam, U., Pulhin, J. M., Razal, R. A., Acosta, R. T., Natividad, M. Q., & Peras, R. J. J. (2006). One century of forest rehabilitation in the Philippines: approaches, outcomes and lessons. In: Chokkalingam, U., Carandang A. P., Pulhin, J. M., Lasco, R. D., Peras, R. J. J., & Toma, T. (eds.), *One Century of Forest Rehabilitation in the Philippines: Approaches, Outcomes and Lessons* (pp. 107–121). Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/002025.

Le, H. D., Smith, C., & Herbohn, J. (2013). What drives the success of reforestation projects in tropical developing countries? The case of the Philippines. *Global Environmental Change, 24*(1), 334–348.

Paclibar, G. C. B., & Tadiosa, E. R. (2020). Plant species diversity and assessment in Quezon Protected Landscape, Southern Luzon, Philippines. *Philippine Journal of Systematic Biology, 14*(3), 1–19.

Quisumbing, E. (1978). Medicinal plants of the Philippines. Forest Research Institute. Katha Pub. Co., Quezon City, Philippines. 1262 p.

Saaty, R. W. (1987). The Analytic Hierarchy Process-What and how it is used. *Mathematical Modelling*, *9*(3–5), 161–176.

Sarmiento, R. T. & Casas, J. V. (2015). GIS-aided suitability assessment of Mt. Mayapay Watershed in Butuan City, Agusan del Norte. *Annals of Studies in Science and Humanities, 1*(1), 46–60.

Schneider, T., Ashton, M. S., Montagnini, F., & Milan, P. P. (2014). Growth performance of sixty tree species in smallholder reforestation trials on Leyte, Philippines. *New Forests, 45*(1), 83–96.

Tadiosa, E. R., Santos, J. M., Cudiamat, M. A., Cruzate, S. M., Arma, E. J. M., Hilapo, D. C., Biscocho, H. H., Saldo, L. A. & Pagadora, R. S. (2016). Analysis of the forest and grassland vegetation at southwestern side of Quezon Protected Landscape, Southern Luzon, Philippines. *IAMURE International Journal of Ecology and Conservation, 19*(1), 53–69.

Tolentino, E. L. Jr. (2008). Restoration of Philippine native forest by smallholder tree farmers. *Smallholder Tree Growing for Rural Development and Environmental Services: Advances in Agroforestry*, *5*, 326–346.

Tolentino, P. J. S., Navidad, J. R. L., Angeles, M. D., Fernandez, D. A. P., Villanueva, E. L. C., Obeña, R. D. R., & Buot, I. E. (2020). Review: Biodiversity of forests over limestone in Southeast Asia with emphasis on the Philippines. *Biodiversitas*, *21*(4), 1597–1613.

Villanueva, E. L. C. & Buot, I. E. Jr. (2017). An enumeration of Hoyas in Quezon Province, Luzon Island, Philippines. T*hailand Natural History Museum Journal, 11*(1), 23–33.

p-ISSN 2012-3612 | e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 | Number 1 | pp. 58-67 | 2023

Predicting the habitat suitability of the Philippine Cockatoo (*Cacatua haematuropygia* S. Muller) using ecological niche factor analysis

Garry M. Oca[1*], Tomas D. Reyes Jr.[1]

[1]*Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. Philippine Cockatoo (*Cacatua haematuropygia* S. Muller) is one of the bird species in the country classified by the International Union for Conservation of Nature (IUCN) as critically endangered. Studies proved that the conservation of wildlife species benefits the economy and biodiversity. Hence, developing strategies to further conserve the Philippine Cockatoo is necessary. One decision-support tool for acquiring ecological and evolutionary insights and predicting species distributions across landscapes is the Species Distribution Model (SDM). This study determined how various environmental variables affect the habitat suitability of the Philippine Cockatoo and generated potential habitat suitability maps of this species using the Ecological Niche Factor Analysis (ENFA), an algorithm that only requires presence and background data. Through the values of marginality, specialization, and tolerance obtained after the modeling, it was found that Philippine Cockatoo prefers an environment that is different from the average condition in the country and lives in a narrow niche. Additionally, the habitat suitability map, which generated optimally suitable habitats for Philippine Cockatoo, is concentrated in some provinces. The five provinces with the highest area of optimal suitable habitat are Palawan, Bohol, Cebu, Negros Oriental, and Siquijor. However, the result could be further improved by adding more occurrence records on Philippine Cockatoo. The findings of this study hold valuable implications for both managers involved in the conservation of the Philippine Cockatoo and future researchers exploring the potential of ENFA for country-wide modeling of Critically Endangered species.

Keywords: biodiversity, marginality, specialization, species distribution model, tolerance

Article Information
Received 20 September 2022
Accepted 14 June 2023
Published online 16 October 2023
*Email: : gmoca@up.edu.ph

INTRODUCTION

The Philippines has gained recognition as one of the 17 megadiverse countries, hosting an extensive range of biodiversity encompassing nearly two-thirds of the world's total, yet the continued destruction of resources led to more than 700 threatened species (Ani & Castillo, 2020). One of the threatened bird species in the country is the Philippine Cockatoo (*Cacatua haematuropygia* S. Muller). The IUCN classified this species as critically endangered (CR), with an estimated population size of about 430 to 750 individuals. This species' population reduction can be attributed to the rampant destruction of lowland forests, their main habitat, and the illegal pet trade (Waugh, 2017).

Philippine Cockatoos are endemic to the Philippines and are typically found in areas adjacent to riverine or coastal areas with mangroves (Widmann *et al.*, 2001). In the past, they were widespread across the Philippines. It is restricted to Palawan and Sulu and appears in Polillo Islands, Samar, and Bohol (Birdlife International, 2021). Conserving the Philippine Cockatoo is crucial because bird species play important ecological roles in the ecosystem (Morante-Filho & Faria, 2017). Like other bird species, the Philippine Cockatoo contributes to seed dispersal, which is vital for maintaining the ecosystem (Godinez-Alvarez *et al.*, 2020). Aside from this, the conservation of the Philippine

Cockatoo has economic benefits as it local and foreign tourists are attracted to birdwatch this species (Manalo *et al.*, 2016).

Habitat suitability pertains to the potential of a particular habitat to support a certain species (Kellner *et al.*, 1992). Predicting the habitat suitability of wildlife using models can be helpful for wildlife managers because, through this, they can identify the preferred and required habitat conditions for a particular species to thrive. One tool that can be used in determining the habitat suitability of a particular species is the Species Distribution Model (SDM) (Haghani *et al.*, 2016). SDMs are numerical tools that link the occurrence or abundance of observed species with environmental estimates to acquire ecological and evolutionary insights.It also predicts distributions across landscapes (Ward *et al.*, 2009).

One of the available SDMs is the Ecological Niche Factor Analysis (ENFA). This SDM algorithm uses occurrence data and environmental variables called presence-background data. SDMs that require these data use locations where individuals have been observed and no longer need information regarding locations where the species are absent (Wang & Stone, 2018). ENFA is a multivariate approach to examining a specific geographic distribution on a large scale. Built on an ecological niche, the model compares the distribution of the sites where the focus species has been observed to a reference set describing the entire study area in the multidimensional space of ecological variables. ENFA condenses all Ecogeographical Variable (EGVs) predictors into several uncorrelated components before creating a habitat suitability map based on eigenvectors and eigenvalues (Hirzel *et al.*, 2002).

Although various conservation efforts are already being applied for Philippine Cockatoo, the concept of SDMs is not included. For instance, SDM was not explored in establishing Philippine Cockatoo critical habitats in Iwahig Prison and Penal Farm in Palawan (Nierves *et al.*, 2017). Aditionally, some conservation program-related activities for the Philippine Cockatoo are focused only on conservation research and education, advocacy, provision of alternative livelihood, habitat restoration, and reintroduction (Katala Foundation, Inc., 2023). Hence, the general objective of this study is to use the SDM algorithm ENFA to predict the habitat suitability of the Philippine Cockatoo. Specifically, it sought to determine how various environmental factors affect the habitat suitability of Philippine Cockatoos in the country. It also aimed to generate a habitat suitability map of the Philippine Cockatoo to gain an idea of areas in the country that needs to be prioritized for protection.

METHODOLOGY

Study site

The available occurrence data of the Philippine Cockatoo shows that it was scattered across three island groups of the Philippines: Luzon, Visayas, and Mindanao. Based on this, the researchers decided to include the entire Philippines as the coverage of the habitat suitability study. Another reason was to maximize the use of the occurrence records of Philippine Cockatoo, which are available online.

The Philippines is located in southeastern Asia with a total area of 300,000 km^2. The geographical characteristics of the Philippines, including its highly diverse topography with mountain ranges predominantly oriented north to south, narrow coastal plains acting as island boundaries, and the presence of inland waters, contribute to its status as one of the most biologically diverse countries in the world (Licuanan *et al.*, 2019). Regarding the climate, the Philippines experiences a reversing monsoon system consisting of the *amihan*, northeastern monsoon, *habagat*, and southwestern monsoon (Licuanan *et al.*, 2019). During the southwest monsoon, rainfall levels are most of the time higher. Forest vegetation in the country had a total of 7,014,156 ha (23.4%) in 2015 (DENR-FMB, 2020). In 2020, the Philippine population was approximately 109,035,343 (PSA, 2020).

Collection of Philippine Cockatoo occurrence data

The Philippine Cockatoo species occurrence data in ground coordinates were acquired from the Global Biodiversity Information Facility (GBIF) website (GBIF.org, 2022). It is an open-source website that provides species occurrence records. In GBIF, the species occurrence data of Philippine Cockatoo in the country that has coordinates was limited to 1881 to 2019, with human observations and preserved specimens as the basis of the record. Another source of occurrence records is the website of eBird (eBird, 2021). Aside from these two sources, locality data where Philippine Cockatoos occurred was collected from the Philippine National Museum (PNM). Each was plotted in the Google Earth Pro software to determine the ground coordinates of these locality data. All the ground coordinates were cleaned by removing points beyond the study area's boundary. Additionally, some ground coordinates too close to each other were readjusted by relocating to areas within the same locality and land cover type. The relocation process was carefully executed to ensure that the new location remained within reasonable proximity to the original point while also considering the topographic and climatic characteristics of the area. **Figure 1** shows the map of the finalized ground coordinates of the Philippine Cockatoo occurrences in the country.

Collection of environmental data

The environmental data considered in the study were classified as climatic factors, topographic factors, vegetative factors, and anthropogenic factors. The data of these parameters were acquired from various online sources (**Table 1**), except for the land cover map, which was requested from the National Mapping and Resource Information Authority (NAMRIA) through email. Since the software intended for ENFA requires quantitative data, numbers were assigned to each land cover type from the land cover maps. The numbers assigned were based on the increasing height of the canopy of the land cover types (Hirzel *et al.*, 2004). After conducting a Principal Component Analysis in ArcMap 10.2.2, the environmental variables with a 70% collinearity were identified

Figure 1. Occurrence map of Philippine Cockatoo.

(Garcia *et al.*, 2013). The percent contribution of each variable from the initial run in the Maxent software was considered to select the variables among the collinear ones. Although all factors went through a multicollinearity test, only certain climatic factors exhibited high collinearity with each other. As a result, the initial set of 19 climatic factors from WorldClim was subsequently reduced to five. Removing highly correlated independent variables was done to avoid overfitting, which may result in too high or negative eigenvalue that can affect the modeling (Hirzel, 2005). Eigenvalues are a special group of numbers connected to a linear system of equations (Hoffman & Kunze, 1971). It provides information on the extent to which the factors explain the variance (Hirzel, 2005).

Species distribution modeling

Before the gathered occurrence records of Philippine Cockatoo and data of environmental variables were entered in the software designated

Table 1. Site characteristics of the Quezon Protected Landscape, site requirements of T*oona calantas*, and the reclassified suitability scores for each site factor.

Classificatio	Variable	Variable unit	Source
Climatic factors	BIO2	Mean diurnal range	WorldClim (worldclim.org, 2023)
	BIO6	Min temperature of the coldest month	
	BIO7	Temperature annual range	
	BIO12	Annual precipitation	
	BIO17	Precipitation of the driest quarter	
Topographic factors	Elevation	Elevation (m)	ASTER from the National Aeronautics and Space Administration (https://lpdaac.usgs.gov/products/astgtmv003/, 2022)
	Slope	Slope (%)	
	dist_river	Distance to roads	Euclidean Distance of Buildings from Geofabrik (https://www.geofabrik.de/, 2023)
Vegetation factors	NDVI	Normalized difference Vegetation index (-1 to 1)	Copernicus Global Land Service (https://land.copernicus.eu/global/index.html, 2023)
	ht_canopy	Height of canopy	Derived from the 2015 Land Cover Map from NAMRIA
Anthropogenic factors	PopDen	Philippine population density	WorldPop (https://www.worldpop.org/, 2023)
	dist_buildings	Distance to buildings (m)	Euclidean Distance of Buildings from Geofabrik (https://www.geofabrik.de/, 2023)
	dist_roads	Distance to roads (m)	Euclidean Distance of Roads from Geofabrik (https://www.geofabrik.de/, 2023)

for ENFA, the occurrence records were first divided. Of all the occurrence records, 30% were sampled randomly through the Microsoft Excel software. This 30% served as test data for assessing the model's accuracy. The remaining 70% was the training data used to build the model (Phillips, 2005). All the acquired occurrences and environmental variable maps were projected to WGS84 UTM Zone 51N.

ENFA, introduced by Hirzel *et al.* (2002), computes habitat-suitability maps by comparing species distribution in eco-geographical variables (EGV) space. It yields two factorial axes: marginality and specialization. Marginality represents the standardized difference between species' average conditions and the study area average. Positive marginality values indicate higher suitability than average conditions. Specialization compares variance across the study area with the species' specific environment, reflecting narrower niche breadth when specialization is high. Habitat suitability maps are constructed by comparing the presence of cell distribution on the factorial axes with cell positions. The software used in the study to perform the algorithm of ENFA is Biomapper 4.0. Since the software requires IDRISI (.rst) as the file format, the environmental factors were converted into .rst format through the ArcRaster feature of TerrSet 18.31. The occurrence points of the Philippine Cockatoo were also converted into a Boolean map using the same feature and software (Hirzel *et al.*, 2004).

The 13 environmental variable maps were inserted in the Biomapper 4.0 as ecogeographical maps (EGV) or the maps that quantitatively describe the study area. The Boolean map of occurrence records was inserted into the software as a working map. Then it was marked as a species map. All the EGV maps were normalized using the Box-Cox transformation feature of the software. After it was normalized, all the EGV maps were verified to ensure they had the same background and non-background cells and to identify the problematic maps (Hirzel *et al.*, 2004).

After preparing all the maps, the automatic analysis feature of Biomapper 4.0 was run. The processes included in the automatic analysis are the generation of the covariance matrix, ENFA, and habitat suitability maps. The method for selecting the number of factors to include in the final mapping was specified using the default Broken-stick method chosen for the process. Also, the algorithm for determining habitat suitability is the median, the software's default. The output set in the automatic analysis are the eigenvalues, score matrix, factor map list, and EGV distributions.

The habitat suitability map produced was in IDRISI file format. Using TerrSet 18.31, it was converted to ASCII file format. Then it was transformed into a shapefile and laid out using ArcMap 10.2.2. An equal interval was used to reclassify the map (**Table 2**). Several studies have used equal intervals in reclassifying suitability maps (Valle *et al.*, 2011; Sahri *et al.*, 2014; Reyes,2015a&b). Using equal interval classification to present the habitat suitability map is advantageous as it simplifies interpretation (Slocum, 2009), facilitating better communication with decision-makers, particularly wildlife managers.

Model validation

The modeling process was performed twice. The first batch was for building the model using the training data, and the second was for validating the model using the test data. Two methods available at Biomapper 4.0 were used to validate the model. The first one was cross-validation with presence-only data. This cross-validation method can provide an idea of the Absolute Validation Index (AVI), Contrast Validation Index (CVI), and the Boyce Index (Hirzel *et al.*, 2004). The value of AVI ranges from 0 to 1 and indicates how well the model can distinguish areas with high and low suitability. The value of CVI ranges from 0 to 0.5 and means how accurate the model is. The value of the Boyce index ranges from -1 to 1 and describes the predictive power of the model (Hirzel *et al.*, 2006).

Cross-validation with the presence or absence of data was the second method to validate the model. This cross-validation method can provide an idea of the threshold-independent area under the curve (AUC) of receiver operating characteristics (ROC). A higher performance model is usually represented by a higher AUC value (**Table 3**).

Table 2. Reclassification of EN A habitat suitability map using equal interval.

Suitability class	Interval
Unsuitable	0-20
Marginal	21-40
Moderate suitable	41-60
Suitable	61-80
Optimal suitable	81-100

Table 3. AUC classification based on Swets (1988)

AUC Value	Description
0.90 - 1.0	Excellent
0.80 –0.90	Good
0.70 - 0.80	Fair
0.60 - 0.70	Poor
Below 0.60	Fail

RESULTS AND DISCUSSION

Marginality, specialization, and tolerance

The overall marginality (M) generated after the modeling is 1.434. This indicates that the habitat of the Philippine Cockatoo is different from the average conditions in the study area. When the value of marginality is closer to 1 or greater than 1, a species can be found in habitats where conditions differ significantly from the average of all habitats surveyed (Liu *et al.*, 2016). The generated specialization (S) value is 1.446, and the tolerance (1/S) value is 0.691, which is an indication of a narrow habitat niche and low tolerance (Paga *et al.*, 2022). When the value of specialization, which ranges from 1 to infinity, becomes higher than 1, the species has a narrower ecological niche (Liu *et al.*, 2016). In addition, if the value of tolerance, which ranges from 0 to 1, is close to 0, a species has a lower tolerance and narrow distribution (Liu *et al.*, 2016). Since the Philippines is a highly diverse country, it is common for species like the Philippine Cockatoo to have a narrow niche. This is due to the intense resource competition among abundant species that leads to niche partitioning (Petruf, 2017). Moreover, small-scale changes in resource composition and structural complexity within these communities further contribute to niche narrowing (Petruf, 2017). The massive decline of the mangrove areas, the preferred habitat of the Philippine Cockatoo, by about half over the past century (Buitre *et al.*, 2019) may have resulted in changes to the available resources for the species, leading to an even narrower niche. Furthermore, the broken-stick advice of ENFA selected the three factors that have the highest contribution to the eigenvalue. These factors are the marginality from factor 1, specialization from factor 2, and specialization from factor 3 (Table 4). The percentage of variance explained by these factors is 13%, 25%, and 14%, respectively. The habitat suitability map was constructed using these three factors due to their combined total exceeding a minimum threshold of 50% (Hirzel, 2005).

In terms of the marginality factor, eight variables had negative values (BIO7, BIO12, BIO17, BIO2, elevation, distroads, NDVI, and slope) and five positives (htcanopy, BIO6, distriver, distbuildings, and slope). A negative value indicates that the species prefer a lower value than the average condition. When the value of the marginality becomes farther from zero, the chosen condition of the species is also becoming farther than the average. The variables with the high absolute value of marginality are BIO7, BIO12, BIO14, BIO6, BIO2, and elevation. Other variables such as NDVI, PopDen, distroads, distbuildings, Slope, distriver, and htcanopy showed an absolute value close to zero, which indicates that they were not significantly different from the average condition of the area (Paga *et al.*, 2022).

Table 4 shows that the climatic factors obtained the highest absolute value of marginality among the environmental factors. However, considering the negative values of most of these climatic factors, these species prefer a lower temperature and precipitation value compared to the country's average. An example of the effect of higher temperature on the Philippine Cockatoo is the observation of wildlife wardens working for the Katala Foundation Incorporated's Philippine Cockatoo Conservation Program. They discovered that young Philippine Cockatoo suffers starvation during dry months because of lack of food (Enaño, 2020). Aside from this, high temperature also negatively affects the mating activity of the Philippine Cockatoo (Widmann *et al.*, 2001). In terms of precipitation, a higher amount of this becomes a threat to Philippine Cockatoo, for it can flood bird nests, wash out eggs, and kill young birds (Saunders, 2022), especially that the preferred habitat of Philippine Cockatoo are areas adjacent to the riverine or coastal areas (Widmann *et al.*, 2001). The two topographic factors (elevation and slope) also obtained a negative value of marginality. This means that the species prefer a lower elevation and slope value than the country's average. The Philippine Cockatoo is mainly found in lowland primary and secondary forests, typically at elevations below 50 m (Birdlife International, 2021). However, the other topographic factor, the distance to the river, has a positive marginality. This means that the species prefer to be closer to water. Despite this, the preference of the Philippine Cockatoo to lower elevation and slope and to be closer to water is in line with the published ecology of the Philippine Cockatoo. This indicates that their typical habitats are lowland forests (Waugh, 2017) and areas adjacent to the riverine or coastal areas (Widmann *et al.*, 2001).

Both the anthropogenic factors (population density, distance to roads, and distance to buildings) and vegetation factors (height of canopy) resulted in a positive value of marginality. This means that they prefer a higher value of various anthropogenic and vegetation factors compared to the average in the country. Based on this, it can be deduced that the Philippine Cockatoo does not perceive interaction with humans as problematic, despite the potential threats humans may pose to them. Various cockatoos were even observed to be close to human settlements (Waugh, 2017). More vegetation is also necessary for birds to have more food sources (Ferger *et al.*, 2014). Food items preferred by Philippine Cockatoos encompass a variety of things such as seeds, fruit, nuts, and berries (O'brien, 2007). Philippine Cockatoo also utilizes vegetation in establishing its nests. Usually, the species construct their nests at an elevation of at least 20 m above the ground. The nest's opening is typically around 20 cm wide, and the hollow space within the nest generally reaches a depth of approximately 1.5 m (O'brien, 2007).

Table 4. Marginality and specialization values of Philippine Cockatoo's ecogeographical variables based on ENFA analysis results.

Ecogeographical variable	M Factor 1	S1 Factor 2	S2 Factor 3
BIO12 (2)	-0.417	0.375	-0.257
BIO17 (3)	-0.410	-0.214	0.375
BIO2 (5)	-0.312	0.703	0.003
BIO6 (4)	0.350	0.182	-0.577
BIO7 (1)	-0.432	-0.522	-0.614
distbuildings (10)	0.057	0.024	-0.072
distriver (8)	0.175	-0.011	-0.098
distroads(11)	-0.043	-0.027	-0.099
Elevation (6)	-0.209	0.088	0.052
htcanopy (7)	0.179	0.054	0.085
NDVI (13)	-0.360	-0.017	0.041
PopDen (12)	0.038	-0.027	0.211
Slope (9)	-0.096	-0.013	-0.039

ENFA habitat suitability map

The habitat suitability map was produced after the modeling was reclassified using equal intervals (**Figure 2**).

The habitat suitability map generated through ENFA shows that 86.21% of the land area in the Philippines is unsuitable habitat for the Philippine Cockatoo. The suitability with the second highest percentage is marginal at 8.42%. It was followed by suitable areas with 2.87%. The fourth one is moderately suitable, with 1.38%. The suitability with the least percentage is the optimal suitability with 1.12%.

The top five provinces that showed the largest area of optimally suitable habitats are Palawan, Bohol, Cebu, Negros Oriental, and Siquijor. Palawan has the largest area, with 229,679.83 ha. It is followed by Bohol, with 19,849.91 ha of land. The third one is Cebu, with 15,915.08 ha. The two with the smallest area among the top 5 highly-suited provinces are Negros Oriental and Siquijor, with land areas of 11,536.88 ha and 10,999.84 ha, respectively. However, regarding the province's total area, Siquijor has the highest percentage of 34.29%. This means that more than three-tenth of the area of this province is an optimal habitat for Philippine Cockatoo.

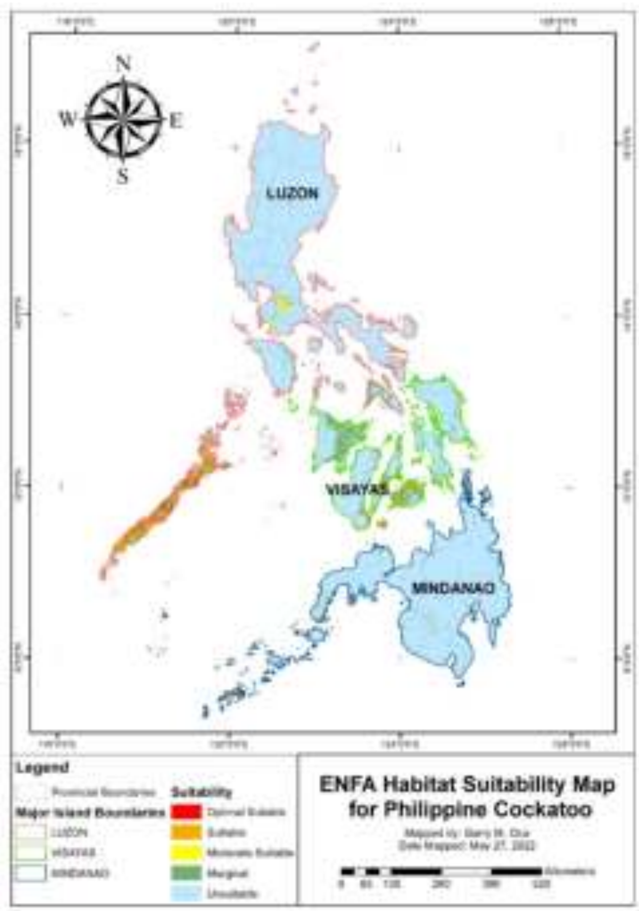


Figure 2. ENFA habitat suitability map for Philippine Cockatoo.

Table 5. Land area (ha) of different suitability.

Suitability	Area (ha)	Percent (%)
Unsuitable	25,007,329.86	86.21
Marginal	2,441,617.36	8.42
Moderate suitable	399,967.60	1.38
Suitable	831,784.28	2.87
Optimal suitable	325,179.02	1.12

Table 6. Top 5 provinces with the largest optimal suitable areas.

Province	Area (ha)	Percentage of the total area of the province (%)
Palawan	138,729.80	9.50
Siquijor	6,693.25	20.87
Negros Oriental	6,622.76	0.85
Bohol	6,084.17	1.53
Sulu	5,976.85	3.83

Model validation

The value obtained for AVI was 0.522. This value means that the model can differentiate areas with high and low suitability. The value obtained for CVI was 0.464, which means that the model is accurate. The value obtained for the Boyce index was 0.188. Since the value of the is positive, the prediction made by the model is consistent with the presence in the evaluation dataset (Hirzel *et al.*, 2006).

The AUC value for test and training data obtained after the ENFA modeling was 0.868 and 0.879, respectively. Even though the AUC value of the test data was lower than the AUC value of the training data, both indicate a good model based on the classification by Swets (1988).

Based on the validation results, it can be inferred that the model accuracy is acceptable, given high CVI and AUC values and moderately high AVI values. It can also be deduced that the not-too-high positive value of the Boyce index was affected by the limited amount of occurrence data used in the modeling since model accuracy can be influenced by the relationship between the size of the calibration area and the area covered by the species occurrences (Santica *et al.*, 2019).

Interpretation of ENFA habitat suitability map

The suitable habitats for Philippine Cockatoo from the model generated were concentrated in some areas in the Philippines. This result is consistent with the marginality, specialization, and tolerance value obtained after modeling these values. This shows that Philippine Cockatoo can be found in habitats where conditions differ significantly from the average of all habitats surveyed and live in a narrow niche. However, one of the possible crucial variables in country-wide modeling is the amount of presence data. The number of occurrence records of Philippine Cockatoos obtained from online sources may also have affected the result of the model. This is because the data obtained through opportunistic observations, like the data from GBIF, or museum records, sometimes have a geographical bias (Dennis & Thomas, 2000). Due to difficult access, unvisited areas in data collection result in incomplete species representation, leading to spatial biases of overrepresentation or underrepresentation (Kadmon *et al.*, 2004). When the occurrence records of the Philippine Cockatoo were mapped, there were areas where the occurrences of Philippine Cockatoos are concentrated, like in Palawan. The overrepresentation and poor representation of Philippine Cockatoos in some areas may have affected the result, especially since the modeling performed was countrywide. Hence, it is necessary to gather more occurrence records of the Philippine Cockatoo to confirm the realness of the result of the modeling.

CONCLUSION

This study predicted the habitat suitability of the Philippine Cockatoo using the whole Philippines as the EGV space. With ENFA, the study gained insights regarding the effects of various environmental variables on the habitat suitability of the Philippine Cockatoo. It was found that Philippine Cockatoo preferred an environmental condition different from the country's average and lived in a narrow niche based on the values of marginality, specialization, and tolerance obtained through the modeling. The study also generated a habitat suitability map of the species. Because of this, the potential of ENFA in producing a country-wide habitat suitability map with satisfactory accuracy is given high values in CVI and AUC and moderately high in AVI, was tested. However, the model produced can still be improved by adding more occurrence records of the Philippine Cockatoo through a more in-depth literature search or survey. The results of this study can be helpful to wildlife managers for them to create more effective plans for the conservation of the Philippine Cockatoo.

LITERATURE CITED

Ani, P. A. B., & Castillo, M. B. (2020). Revisiting the state of Philippine biodiversity and the legislation on access and benefit sharing. *FFTC Journal of Agricultural Policy*.

BirdLife International. (2021). Species factsheet: Cacatua haematuropygia. Retrieved from: <http://www.birdlife.org>.

Buitre, M., Zhang, H., & Lin, H. (2019). The mangrove forests change and impacts from tropical cyclones in the Philippines using time series satellite imagery. *Remote Sensing*, *11*(6), p. 688). *MDPI AG*. https://doi.org/10.3390/rs11060688.

Dennis, R. &Thomas, C. D. (2000). Bias in butterfly distribution maps: the influence of hot spots and recorder's home range. *Journal of Insect Conservation*, *4*, 73–77.

DENR – FMB [Department of Environment and Natural Resources – Forest Management Bureau]. (2020). Philippine Forestry Statistics.

eBird. (2021). eBird: An online database of bird distribution and abundance [web application]. eBird, Cornell Lab of Ornithology, Ithaca, New York. Retrieved on December 2021, from: <http://www.ebird.org>.

Elith, J. & Franklin, J. (2013). Species distribution modeling. *In: Encyclopedia of Biodiversity* (pp. 692–705). Elsevier. https://doi.org/10.1016/b978-0-12-384719-5.00318-x.

Enaño, J. O. (2020). PH Cockatoo Hatching on Wild Gives Hope. Retrieved from: <https://faspselib.denr.gov.ph/sites/default/files//200824_MB_Enaño_PH%20cockatoo%20hatchling%20in%20wild%20gives%20hope.pdf>.

Ferger, S. W., Schleuning, M., Hemp, A., Howell, K. M., & Böhning-Gaese, K. (2014). Food resources and vegetation structure mediate climatic effects on species richness of birds. *Global Ecology and Biogeography*, *23*(5), 541–549.

Garcia, K., Lasco, R., Ines, A., Lyon, B., & Pulhin, F. (2013). Predicting geographic distribution and habitat suitability due to climate change of selected threatened forest tree species in the Philippines. *Applied Geography*, *44*, 12–22.

GBIR.org. (2022). GBIF Occurrence Download. https://doi.org/10.15468/dl.7xta8j

Godínez-Alvarez, H., Ríos-Casanova, L., & Peco, B. (2020). Are large frugivorous birds better seed dispersers than medium- and small-sized ones? Effect of body mass on seed dispersal effectiveness. *Ecology and Evolution*, *10*(12), 6136–6143.

Haghani, A., Aliabadian, M., Sarhangzadeh, J., & Setoodeh, A. (2016). Seasonal habitat suitability modeling and factors affecting the distribution of Asian Houbara in East Iran. *Heliyon*, *2*(8), e00142. https://doi.org/10.1016/j.heliyon.2016.e00142.

Hirzel, A. H., Le Lay, G., Helfer, V., Randin, C., & Guisan, A. (2006). Evaluating the ability of habitat suitability models to predict species presences. *Ecological Modelling*, *199*(2), 142–152.

Hirzel, A. (2005). Frequently Asked about Biomapper. Retrieved from: <https://www2.unil.ch/biomapper/Biomapper%20FAQ.pdf>.

Hirzel, A. H., Posse, B., Oggier, P.-A., Crettenand, Y., Glenz, C., & Arlettaz, R. (2004). Ecological requirements of reintroduced species and the implications for release policy: the case of the bearded vulture. *Journal of Applied Ecology*, *4*(16), 1103–1116.

Hirzel, A. H., Hausser, J., Chessel, D., & Perrin, N. (2002). Ecological-niche factor analysis: How to compute habitat-suitability maps without absence data? *Ecology*, *83*(7), 2027–2036.

Hoffman, K. & Kunze, R. (1971). Characteristic values. Linear Algebra, 182–190.

Kadmon, R., Farber, O., & Danin, A. (2004). Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. *Ecological Applications*, *14*, 401–413.

Katala Foundation, Inc. (2023). Philippine Cockatoo Conservation Program. Retrieved from: <https://katalafoundation.org)/pccp/philippine-cockatoo-conservation-program/.>

Kellner, C. J., Brawn, J. D., & Karr, J. R. (1992). What is habitat suitability and how should it be measured? *In: Wildlife 2001: Populations* (pp. 476–488). Springer Netherlands. https://doi.org/10.1007/978-94-011-2868-1_36.

Licuanan, W. Y., Cabreira, R. W., & Alino, P. M. (2018). *The Philippines. World Seas: An Environmental Evaluation Volume II: The Indian Ocean to the Pacific*, 515–537. https://doi.org/10.1016/B978-0-08-100853-9.00051-8.

Liu, P., Wen, H., Lin, L., Liu, J., & Zhang, L. (2016). Habitat evaluation for Asian elephants (Elephas maximus) in Lincang: Conservation planning for an extremely small population of elephants in China. *Biological Conservation, 198*, 113–121.

Manalo, R. I., Roa, S. A., Cadigal, G. M., Jalover, C. L. S., Dela, M. A. V., Cruz, R. M., ... & Cabanillas, W. (2016). Our Palawan. *The Scientific Journal of Palawan Council for Sustainable Development*, *2*(1).

Morante-Filho, J. C. & Faria, D. (2017). An appraisal of bird-mediated ecological functions in a changing world. *Tropical Conservation Science, 10*, 194008291770333. doi:10.1177/1940082917703339.

Nierves, M., Tinay, K., Widmann, P., Widmann, I. D., & City, P. P. (2017). Conservation of the Philippine Cockatoo *Cacatua haematuropygia* and its habitat in Iwahig Prison and Penal Farm (IPPF) Palawan, Philippines. PCCP-IPPF technical progress report: January to June.

O'Brien, J. (2007). EEP Husbandry Guidelines for Cacatua Spp. (2nd Edition).

Paga, B., Pudyatmoko, S., Wijayanti, L. R., Yuda, P., & Sulaksono, N. (2022). The habitat suitability of Timor friarbird (Philemon inornatus) in Western Timor Island, Indonesia. Biodiversitas *Journal of Biological Diversity, 23*(2). UNS Solo. https://doi.org/10.13057/biodiv/d230215.

Petruf, M. (2017). Niche Partitioning in Tropical Birds. Bachelor Thesis. Prague. Retrieved from: <https://dspace.cuni.cz/bitstream/handle/20.500.11956/87541/BPTX_2016_1_11310_0_445099_0_184966.pdf?sequence=1&isAllowed=y>.

PSA. [Philippine Statistics Authority]. (2020). Household Population, Number of Households, and Average Household Size of the Philippines (2020 Census of Population and Housing). Retrieved from: <https://psa.gov.ph/population-and-housing/node/166426>.

Phillips, S. J. (2005). A brief tutorial on Maxent. *AT&T Research*, *190*(4), 231–259.

Reyes, T. D., Jr. (2015a). Comparison of semi-quantitative and statistical regression models in assessing landslide prone areas in Wahig-Inabanga Watershed, Bohol, Philippines. *International Journal of Environmental and Rural Development, 6*(2), 166–171.

Reyes, T. D., Jr. (2015b). Evidence-based modeling of landslide hazard in Wahig-Inabanga Watershed, Bohol, Philippines using GIS and statistical models. *International Journal of Environmental and Rural Development, 6*(2), 178–184.

Sahri, A., Anggoro, S., & Suprijanto, J. (2014). Habitat suitability modeling of Asian-Moon scallop (Amusium pleuronectes) in Brebes District Waters, Central Java, Indonesia. *International Journal of Marine Science, 4*(61), 1–13.

Saunders, S. (2020). As the Climate Changes, How Will Birds Weather Heavier Rains and Snows? Retrieved from: <https://www.audubon.org/news/as-climate-changes-how-will-birds-weather-heavier-rains-and-snows>.

Slocum, T. A. (2009). Thematic Cartography and Geovisualization. Pearson Prentice Hall: Upper Saddle River, NJ. p. 60.

Swets, J. A. (1988). Measuring the accuracy of diagnostic systems. *Science*, 240(4857), 1285–1293.

Valle, M., Borja, Á., Chust, G., Galparsoro, I., & Garmendia, J. M. (2011). Modelling suitable estuarine habitats for Zostera noltii, using Ecological Niche Factor Analysis and Bathymetric LiDAR. *Estuarine, Coastal and Shelf Science, 94*(2), 144–154.

Wang, Y. & Stone, L. (2018). Understanding the connections between species distribution models for presence-background data. *Theoretical Ecology*, *12*(1), 73–88.

Ward G., Hastie, T., Barry, S. C., Elith, J., & Leathwick, J. R. (2009). Presence-only data and the EM algorithm. *Biometrics*, 65, 554–563.

Waugh, D. (2017). Loro Parque Fundación backs Katala in more conservation successes for the Philippine Cockatoo. *AFA Watchbird*, *44*(2), 42–47.

Widmann, P., Widmann, L., & Diaz, S. (2001). Aspects of ecology and conservation of the Philippine cockatoo *Cacatua haematuropygia* on Rasa Island, Palawan, Philippines. *Siliman Journal*, *42*, 129–148.

p-ISSN 2012-3612 │ e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Threatened Philippine plants in the Makiling Botanic Gardens: A preliminary assessment

Leilani A. Castillo[1*], Manuel L. Castillo[2], Leonardo D. Barua[1], Myranel S. Canceran[1], Ma. Ruffa P. Guab[1], Marlo M. Caña[1], Mae Belen L. Putian[1], Gillian Katherine I. Quilloy[1], Angela A. Limpiada[1], Aldin C. Alegre[1], Aldwin L. Labuanan[1], Ozzy Boy S. Nicopior[1], Karla Jane P. Gonzalvo[1], Marilyn O. Quimado[2], Edwino S. Fernando[2]

[1]*Makiling Center for Mountain Ecosystems, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines;*
[2]*Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. The inventory of threatened plants inside the Makiling Botanic Gardens (MBG), Mount Makiling Forest Reserve ASEAN Heritage Park (MMFR AHP) was conducted. The study aims to identify and assess Philippine threatened species based on the DENR Administrative Order 2017-11, including their status, number, and spatial distribution within the area. Following the GIS-Based Assessment, Monitoring, and Evaluation (GAME) Model gridding system, the inventory covered 6.9 ha. The covered area comprises about 2.3% of the 300-ha area of MBG, including the Gardens, the Mudsprings, and the Makiling Rainforest Park (MRP). Trees with a minimum diameter at breast height (DBH) of 5.0 cm were measured and mapped. Vines and orchids were counted and noted. Results of the initial inventory showed a diverse collection of threatened species. A total of 428 species, with 7,657 individuals, were inventoried. Of these, 110 species from 78 genera belonging to 37 families were recorded to be Philippine threatened plant species: 11 are categorized as critically endangered (CR), 21 species are endangered (EN), 53 species are vulnerable (VU), and 25 species are considered other threatened species (OTS). This represents about 11% of the 984 species in the Philippine threatened plant list. About 42% of these threatened species are endemic to the Philippines. Among the MMFR AHP's points of interest, the Gardens has the most significant number of threatened species, followed by the Mudsprings and MRP. The results give the MBG its initial list of documented threatened species. The MBG should prioritize the conservation of its threatened species, including habitats, and implement programs to increase its living collections and develop propagation protocols to make these available for recovery and restoration programs. The study recommends conducting a continuous inventory of all threatened species in MBG.

Keywords: conservation, inventory, living collections, priority species

Article Information
Received 05 July 2022
Accepted 26 May 2023
Published online 16 October 2023
*Email: lacastillo@up.edu.ph

INTRODUCTION

Conservation of threatened species is both a national and global concern. Targets 7 and 8 of the Global Strategy for Plant Conservation (GSPC) focus on conserving threatened plants (Convention on Biological Diversity, 2012). The Philippines, with regards to the conservation of threatened plants, has the Philippine Biodiversity Strategy and Action Plan (PBSAP), which embodies the 206 conservation priority areas, 228 key biodiversity areas, and 20 targets towards human well-being with Target 1 focusing on the maintenance and improvement on the conservation of threatened plants (DENR-BMB, 2016). Data showed a 30% increase in threatened plants from 686 species (DENR DAO, 2007-01) to 984 (DENR DAO, 2017-11).

These threatened species are mostly found in key biodiversity areas (KBAs). The KBAs were established to prioritize conservation action and develop strategies to protect threatened species, including their representative habitats (Edgar *et al.*, 2008). The Mount Makiling Forest Reserve ASEAN Heritage Park (MMFR AHP) is declared one of the KBAs. Along with other KBAs, there is a need to undertake a range of conservation activities to safeguard threatened species. MMFR AHP is known for its diverse biological resources (Pancho, 1983; Gruezo, 1997; Bantayan *et al.*, 2008; Lapitan *et al.*, 2010; Castillo *et al.*, 2018) and home to many native and endemic species including the popular *Medinilla magnifica* Lindl., *Strongylodon macrobotrys* A.Gray, and *Rafflesia lagascae* Blanco (Fernando *et al.*, 2004).

The Makiling Botanic Gardens (MBG) is a facility within the MMFR AHP. It serves as a show window of MMFR AHP, especially for those unable to go around the reserve. The MBG, as mandated by Republic Act (RA) No. 3523 in 1963, functions mainly to support instruction and research related to forestry and plant sciences and to serve the public's educational, recreational, and tourism needs. Unlike many typical botanic gardens, the MBG houses living collections and a natural forest. It also serves as a repository of important and rare endemic, native, and exotic species.

MBG contains theme gardens and arboreta that showcase a diverse plant collection, including threatened plants. With the establishment of the Philippine red list of threatened species and the inclusion of MMFR to KBA, there is a great need to inventory the plants found within MBG and identify the threatened species to prioritize their conservation and protection. Currently, MBG has no documented list of threatened species. The list will provide reference material for future germplasm sources, especially for those species in the critically endangered category.

The study aimed to provide MBG's initial list and information on the threatened plants, such as status, their number, and spatial distribution. The results will significantly help as this will complement the conservation efforts in target species, habitats, ecosystems, and priority areas in MBG. Further, this will provide additional information and reference for the global conservation of these crucial species.

METHODOLOGY

Location of the study

The inventory of threatened species composed of vines, shrubs, palms, orchids, climbers, and trees, was conducted in August 2019 – September 2020 as part of the Department of Science and Technology's funded project entitled "*Ex-situ* Conservation of Threatened Philippine Plants: Restoring Philippines' Plant Resources and Environment." The study is located at MBG, which occupies 300 ha of natural and re-growth forests on the northeastern slope of MMFR AHP. This comprises MMFR's points of interest, such as the Gardens, the Mudsprings, and MRP (**Figure 1**). Furthermore, the inventory lasted for about a year and covered approximately 6.9 ha of forest floor area, which comprises about 2.3% of the whole area of MBG.

Inventory design and layout

The forest inventory conducted at MBG was guided by GIS-Based Assessment, Monitoring, and Evaluation (GAME) Model gridding system (Bantayan *et al.*, 2008). This model has been the basic unit of field-based assessments in all projects conducted by the Makiling Center for Mountain Ecosystems (MCME). The Center is mandated to conduct research and demonstration programs on mountain ecosystem development and formulate and execute plans for sustainable management of the MMFR.

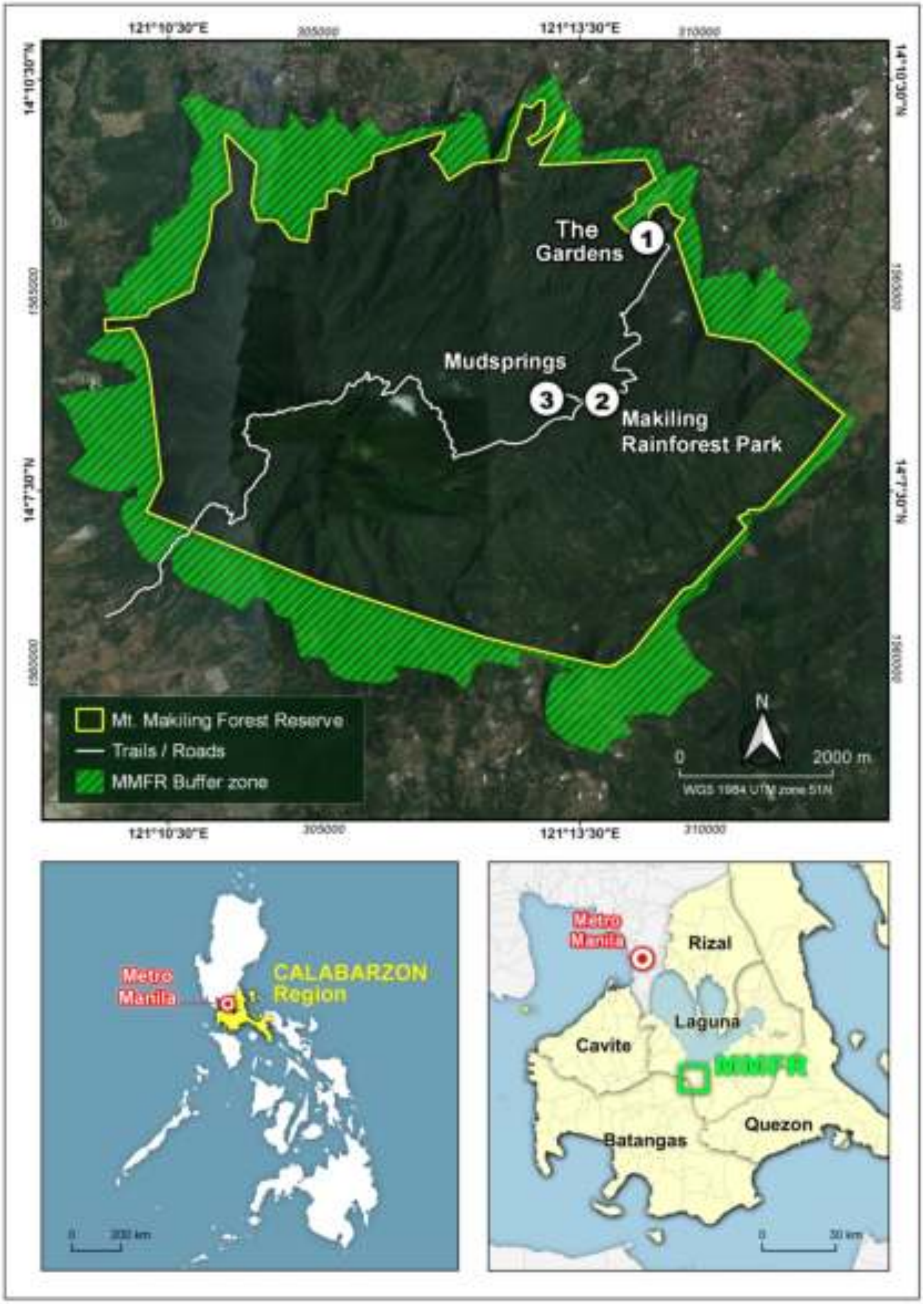


Figure 1. The Makiling Botanic Gardens zone (The Gardens, Makiling Rainforest Park, and Mudspring within the Mount Makiling Forest Reserve ASEAN Heritage Park).

Within the GAME model gridding system, a nested vector grid contains five details ranging from 1 km^2 to 10 m^2 (**Figure 2**). Planning fieldwork was carried out on larger grids, while data collected onsite was tagged based on the finer granules of the gridding system. This system allowed MCME to aggregate observations and produce larger-scale analyses such as land cover determination as needed. Contained within the granules were individual point locations of trees inventoried in a portion of MBG.

Inventory of threatened species

All trees with a minimum diameter at breast height of 5.0 cm were measured and recorded, including total and merchantable heights. Vines, orchids, and climbers were counted and noted. Instruments such as diameter tape and range finder were used during the inventory. The relative location of each plant was also determined using Geographic Information System (GIS). Voucher specimens were collected for identification, authentication, and herbarium collection and deposited at the Forestry Herbarium, Department of Forest Biological Sciences (DFBS), College of Forestry and Natural Resources (CFNR), University of the Philippines Los Baños (UPLB).

Species identificatio

Identification of species was based mainly on morphological characteristics such as leaves, flowers, fruits, seeds, stems, bark, and other characteristics that may help to identify the plant species. Herbarium specimens (including digital images) and DFBS, CFNR, UPLB experts were also consulted.

Categorization of threatened species

From the generated inventory data, threatened species were identified and categorized based on DAO 2017-11 or the Updated National List of Threatened Philippine Plants and their Categories. The study used DAO 2017-11 as the main reference since this is the country's prevailing national red list.

RESULTS AND DISCUSSION

Distribution and status of threatened plants

Results of the initial inventory showed a diverse collection of threatened species. A total of 110 species from 78 genera belonging to 37 families were recorded to be Philippine threatened plant species: 11 species in the critically endangered

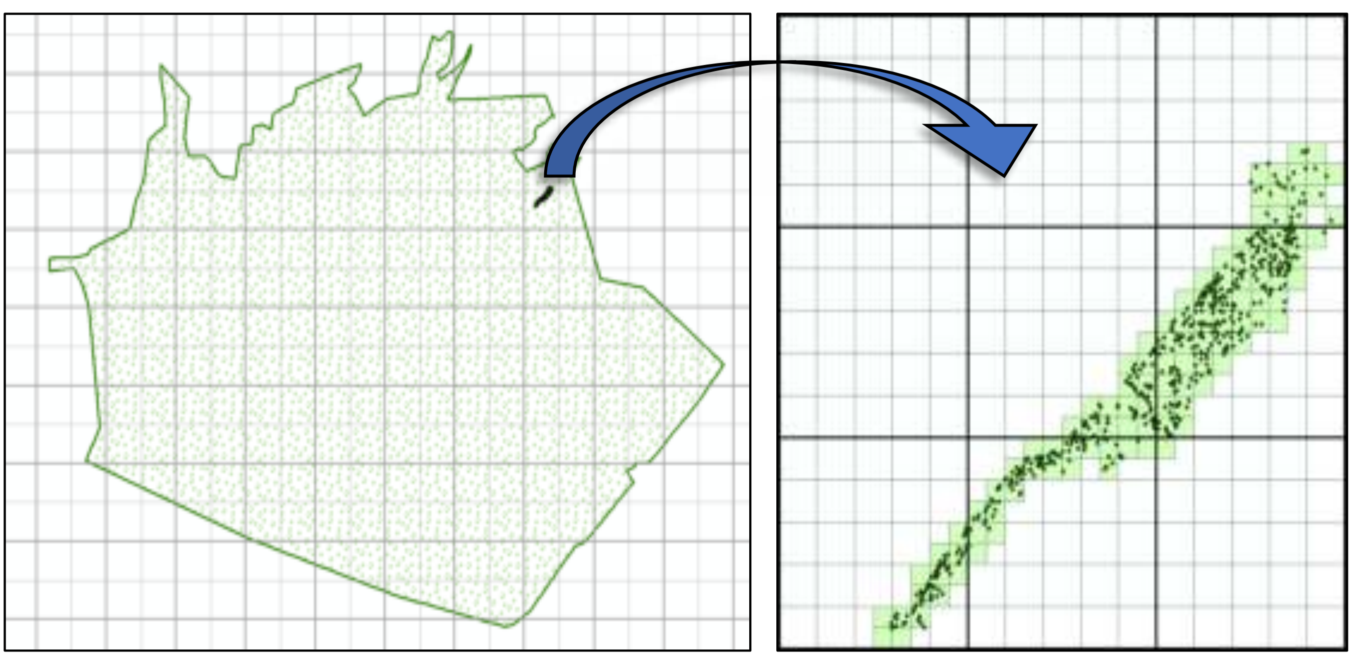


Figure 2. Inventory design and layout using GIS-based assessment, monitoring, and evaluation (GAME) model gridding system.

(CR) category, 21 endangered (EN) species, 53 vulnerable (VU) species, and 25 other threatened species (OTS) (**Table 1**).

About 42% of the identified threatened species are endemic to the Philippines (**Table 1**). Data also revealed that most threatened species fall under the VU category. Among other ASEAN Heritage Parks, MBG has the highest percentage of endemism, followed by Mount Hamiguitan Range Wildlife Sanctuary (MHRWS) (34%), Mount Kitanglad Range Natural Park (MKRNP) (21%), and Mount Malindang Range Natural Park (MMRNP) (16%) (Amoroso *et al.*, 2011). In terms of the number of threatened species, MBG still has the most significant share of threatened species at 110, followed by MKRNP (92 species), MHRWS (35), and MMRNP (34).

Like the MBG, other botanic gardens in Southeast Asia house threatened species in their area. The Queen Sirikit Botanic Gardens (QSBG) in Chang Mai, Thailand, and Singapore Botanic Gardens (SBG) in Singapore keep threatened orchids. SBG recorded 226 species of native orchids. Of these, 178 are considered to be extinct, 40 are CR, one is EN (*Bulbophyllum vaginatum* Rchb.f.), and two are VU (*Vanilla griffithii* Rchb.f., *Bulbophyllum trifolium* Ridl.) (Yam *et al.*, 2010). Meanwhile, the QSBG contains 78 genera and 300 species of Thai native orchids deposited and looking well at their nurseries. Of these, 60 and 20 species are considered rare and EN, respectively (Nanakorn & Indharamusika, 1997). The Bogor Botanic Gardens (BBG) in Bogor, Indonesia, the oldest botanic garden among them, also shares a list of threatened species (Ariati & Widyatmoko, 2019). BBG listed 36 threatened species belonging to the family Dipterocarpaceae. The list includes *Upuna*, a monotypic genus endemic to Borneo, with its single species *Upuna borneensis* Symington and the rest are mostly *Dipterocarpus, Hopea*, and *Shorea* species (BGCI, u.d.). Regarding plant habit, the study documented 86 trees, 10 palms, six orchids, four epiphytes, two herbs, one vine, and one climber (**Figure 3**). The distribution reflects the dominance of trees since about 90% of MBG's natural landscape is forest, and more trees are being planted since they have the most readily available planting materials in the area.

The families of Dipterocarpaceae and Arecaceae have the most threatened species since the living collections comprising these families are among the first established in MBG. Also, the existence of the Dipterocarp Forest at about 600 m elevation of the mountain (Brown, 1919) and the Dipterocarp mix-montane forest zone (Gruezo, 1997) in MMFR provided an excellent and accessible venue for germplasm collection.

The threatened species form part of the natural landscape of MBG. The threatened species are not only used for living collections but also for

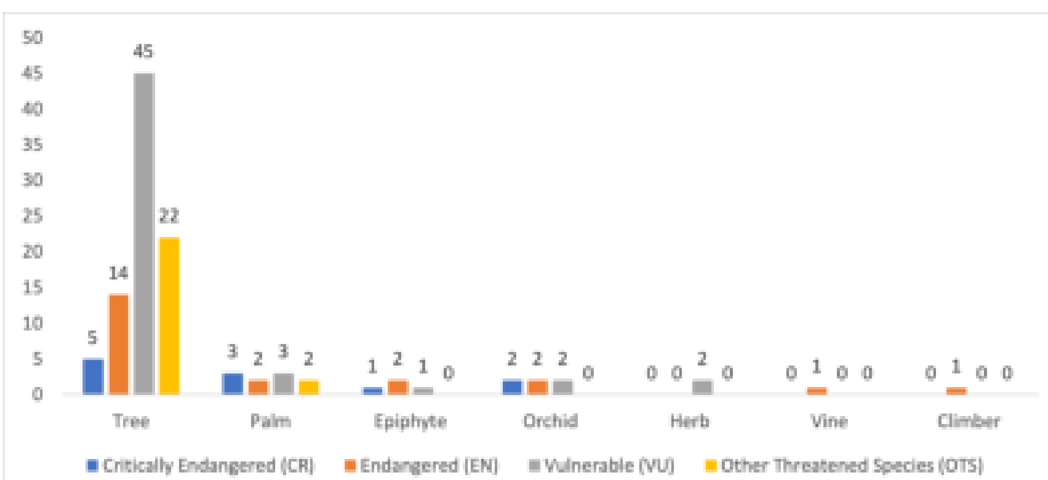


Figure 3. Distribution of threatened plants per plant habit.

communication, education, and public awareness in line with the MBG's function as a training laboratory for instruction, research, and extension. These living collections of threatened plants are being shared with the UPLB community and with all MBG's local and international visitors and plant enthusiasts to increase awareness of the importance of conserving and protecting these threatened species.

List and spatial distribution of threatened species in MBG

The initial list and spatial distribution of 110 threatened plants within the MBG are shown in **Table 1** and **Figure 4**. The Garden recorded the most threatened species since it is the central repository of threatened species in MBG, followed by Mudsprings and MRP (**Figure 4**). As the most accessible among the MMFR's three points of interest, the Gardens is the most frequently visited for education and recreation, hence more activities focusing on plant conservation, interpretation, and appreciation.

Of the 11 species recorded as CR, eight are Philippine endemic. Notable species under this category include *Medinilla magnifica* Lindl., *Heterospathe califrons* Fernando, *Heterospathe scitula* Fernando, *Pinanga bicolana* Fernando, *Hopea malibato* Foxw., *Hopea philippinensis* Dyer, and *Vanda sanderiana* Rchb.f. *M. magnifica* is MBG's emblem since its description was based on collected samples on Mount Makiling in 1800. Most critically endangered species are found within the Gardens' recreation area, nursery, and Dipterocarp arboretum.

Under the EN category, 21 species were listed. Similar to CR species, 13 are Philippine endemic under this category. Notable and rare hardwood species include *Hopea acuminata* Merr., *Sindora supa* Merr., *Tectona philippinensis* Benth. & Hook., and *Litsea leytensis* Merr. Most of these EN species are found within the Gardens and at higher elevations (300-400 m asl), such as Mudsprings and MRP.

A total of 53 threatened species in MBG fall under the VU category. Notable species include endemic species such as *Areca ipot* Becc., *Cycas riuminiana* Porte ex Regel, *Dillenia luzoniensis* (S.Vidal) Merr., *Palaquium philippense* (Perr.) C.B.Rob., and *Reutealis trisperma (*Blanco) Airy Shaw. Most of these species are evergreen and commonly growing in low and medium elevations. *P. philippense* is the most widespread species in the Sipit Watershed, one of the major MMFR watersheds, as Brown (1919) reported in Castillo *et al.* (2021).

The OTS also represents 25 species. Under this category are endemic species such as *Artocarpus rubrovenius* Warb., *Canarium ovatum* Engl., *Cinnamomum mercadoi* Vidal, *Mitrephora lanotan* (Blanco) Merr., *Myristica philippensis* Lam., and *Ziziphus talanai* (Blanco) Merr. Most of these OTS species are medium-large trees and used for light construction. Further, they are commonly found at low-medium altitudes, such as *C. ovatum*, widely cultivated and used commercially for making confectionary and bakery products (Fernando *et al.*, 2004).

The number of threatened species in MBG can be attributed to the gardens' natural landscape improvements. These include botanical exploration and germplasm collection, establishing theme gardens, and maintaining natural regenerations as part of MBG's *ex-situ* and *in-situ* conservation programs. Infrastructure development occurred partly in MBG from 1965 to 1967, including plant nursery and foot trail construction. Collections of seeds and seedlings of important endemic trees also commenced. Immediately after that, dipterocarp, palmetum, and leguminous blocks were developed, and intensive research activities focusing on the germination and growth of endemic and native tree species were also undertaken.

Since the garden's establishment in 1963, germplasm collections have been conducted within and outside the MMFR. Its most extensive collection outside the MMFR was in 1997 when the Department of Tourism provided financial assistance in collecting plant species to improve and establish its living collections. The continuous *in-situ* and *ex-situ* conservation programs have managed and conserved these threatened plants inside the garden.

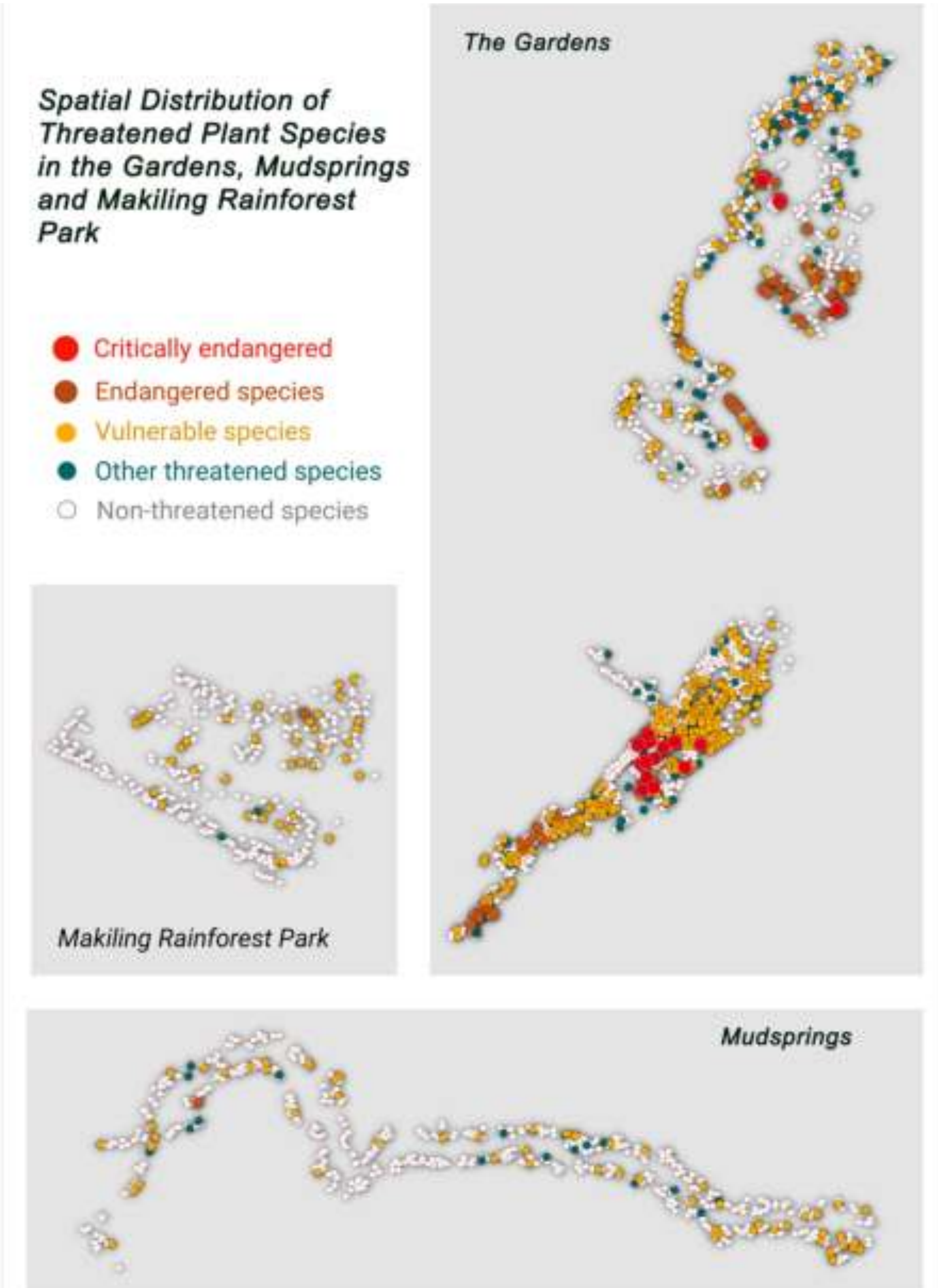


Figure 4. Spatial distribution of Philippine threatened plants found within MBG zone.

Table 1. Initial list of Philippine threatened species recorded in the Makiling Botanic Gardens

No.	Accession code	Family*	Scientific name	Common name	Plant Habit	Threat Category DAO 2017-11	Threat Category IUCN 2022-1	Endemicity**	N
1	ADEINTFAB2020.00455	FABACEAE	*Adenanthera intermedia* Merr.	Tanglin	Tree	OTS	VU	Endemic	8
2	ADOMERARE2020.00473	ARECACEAE	*Adonidia merrillii* (Becc.) Becc.	Manila Palm	Palm	VU	VU	Native	78
3	AFZRHOFAB2019.00386	FABACEAE	*Afzelia rhomboidea* S.Vidal	Tindalo	Tree	EN	VU	Native	7
4	AGAPHIARA2021.00487	ARAUCARIACEAE	*Agathis philippinensis* Warb.	Almaciga	Tree	VU	VU	Native	6
5	AGLEDUMEL2019.00413	MELIACEAE	*Aglaia edulis* (Roxb.) Wall.	Malasaging	Tree	OTS	NT	Native	14
6	AGLRIMMEL2022.00627	MELIACEAE	*Aglaia rimosa* (Blanco) Merr.	Bayanti	Tree	OTS	NT	Native	9
7	ALALONFAB2021.00484	CORNACEAE	*Alangium longi lorum* Merr.	Malatapai	Tree	OTS	VU	Native	38
8	ALOZEBARA2021.00558	ARACEAE	*Alocasia zebrina* Schott ex Van Houtte	Gabing Tigre	Herb	VU	NE	Endemic	1
9	ALPELEZIN2021.00493	ZINGIBERACEAE	*Alpinia elegans* (C.Presl) K.Schum.	Tagbak	Herb	VU	NE	Endemic	1
10	ANGEVEMAR2021.00770	MARATTIACEAE	*Angiopteris evecta* (Forst.) Hoffm.	Fern	Tree	OTS	NE	Native	2
11	ANISCADIP2021.00763	DIPTEROCARPACEAE	*Anisoptera scaphula* (Roxb.) Kurz	Tree	Tree	VU	EN	Native	1
12	APHPOLMEL2020.00462	MELIACEAE	*Aphanamixis polystachya* (Wall.) R.Parker	Kangko	Tree	OTS	LC	Native	20
13	ARDSQUMYR2019.00369	MYRSINACEAE	*Ardisia elliptica* Thunb	Tree	Tree	VU	VU	Native	10
14	ARECAMARE2021.00758	ARECACEAE	*Areca camarinensis* Becc.	Mono	Palm	EN	NE	Endemic	3
15	AREIPOARE2019.00385	ARECACEAE	*Areca ipot* Becc.	Bungang ipod	Palm	VU	EN	Endemic	2
16	ARTRUBMOR2020.00480	MORACEAE	*Artocarpus rubrovenius* Warb.	Kalulot	Tree	OTS	NE	Endemic	22
17	BALLUZEUP2020.00459	EUPHORBIACEAE	*Balakata luzonica* (S.Vidal) Esser	Balakat Gubat	Tree	VU	NE	Native	42
18	CALMERARE2021.00485	ARECACEAE	*Calamus merrillii* Becc	Palasan	Climber	OTS	NE	Endemic	1
19	CAMLANTHE2021.00767	THEACEAE	*Camellia lanceolata* (Blume) Seem.	Haikan	Tree	VU	LC	Native	1
20	CANLUZBUR2021.00542	BURSERACEAE	*Canarium luzonicum* (Blume) A. Gray	Piling liitan	Tree	OTS	NT	Native	39
21	CANOVABUR2021.00500	BURSERACEAE	*Canarium ovatum* Engl.	Pili	Tree	OTS	LC	Endemic	24
22	CARBRARHI2020.00472	RHIZOPHORACEAE	*Carallia brachiata* (Lour.) Merr.	Bakauan gubat	Tree	OTS	NE	Native	6
23	CINMERLAU2021.00539	LAURACEAE	*Cinnamomum mercadoi* S.Vidal	Kalingag	Tree	OTS	LC	Endemic	3
24	CLEQUALAM2021.00489	LAMIACEAE	*Clerodendrum quadriloculare* (Blanco) Merr.	Bagauak-morado	Tree	VU	LC	Native	1
25	CRYAMPLAU2021.00765	LAURACEAE	*Cryptocarya ampla* Merr.	Bagarilau	Tree	VU	LC	Native	1
26	CUBCUBSAP2021.00761	SAPINDACEAE	*Cubilia cubili* (Blanco) Adelb.	Kubili	Tree	EN	LC	Native	2

Table 1. (Con't)

No.	Accession code	Family*	Scientific name	Common name	Plant Habit	Threat Category DAO 2017-11	IUCN 2022-1	Endemicity**	N
27	CYCRIUCYC2021.00486	CYCADACEAE	*Cycas riuminiana* Porte ex Regel	Bayit	Tree	VU	EN	Endemic	3
28	DILLUZDIL2020.00431	DILLENIACEAE	*Dillenia luzoniensis* (S.Vidal) Merr.	Malakatmon	Tree	VU	VU	Endemic	2
29	DILREIDIL2019.00409	DILLENIACEAE	*Dillenia reifferscheidia* Fern.-Vill.	Katmon Kalabaw	Tree	OTS	NT	Endemic	1
30	DIOCAUEBE2021.00764	EBENACEAE	*Diospyros cauliflora* Blume	Aponan	Tree	VU	NE	Native	1
31	DIODISEBE2019.00443	EBENACEAE	*Diospyros discolor* Willd.	Kamagong	Tree	VU	NE	Native	18
32	DIOFEREBE2020.00451	EBENACEAE	*Diospyros ferrea* (Willd.) Bakh.	Ebony	Tree	VU	NE	Native	6
33	DIOPHIEBE2020.00479	EBENACEAE	*Diospyros philippinensis* A.DC.	Oi-oi	Tree	VU	NT	Native	1
34	DIOPILEBE2021.00506	EBENACEAE	*Diospyros pilosanthera* Blanco	Bolong eta	Tree	VU	NE	Native	5
35	DIOPONEBE2021.00569	EBENACEAE	*Diospyros poncei* Merr.	Ponce Kamagong	Tree	CR	EN	Native	1
36	DIOPYREBE2021.00516	EBENACEAE	*Diospyros pyrrhocarpa* Miq.	Anang	Tree	VU	LC	Native	25
37	DIPALADIP2021.00497	DIPTEROCARPACEAE	*Dipterocarpus alatus* Roxb. ex G.Don.	Hairy-leaf apitong	Tree	VU	VU	Native	34
38	DIPCAUDIP2021.00581	DIPTEROCARPACEAE	*Dipterocarpus caudatus* Foxw.	Tailed-leaf apitong	Tree	VU	LC	Native	59
39	DIPGRADIP2019.00392	DIPTEROCARPACEAE	*Dipterocarpus gracilis* Blume	Panau	Tree	VU	LC	Native	37
40	DIPGRADIP2021.00512	DIPTEROCARPACEAE	*Dipterocarpus grandiflorus* Blanco	Apitong	Tree	VU	EN	Native	155
41	DIPKERDIP2019.00399	DIPTEROCARPACEAE	*Dipterocarpus kerrii* King	Malapanau	Tree	EN	EN	Native	7
42	DIPKUNDIP2021.00593	DIPTEROCARPACEAE	*Dipterocarpus kunstleri* King	Broad-winged apitong	Tree	VU	CR	Native	1
43	DRADAOANA2019.00441	ANACARDIACEAE	*Dracontomelon dao* (Blanco) Merr.	Dao	Tree	VU	LC	Native	47
44	DRYFALPUT2019.00402	PUTRANJIVACEAE	*Drypetes falcata* (Merr.) Pax & K. Hoffm.	Gakakan	Tree	OTS	NE	Endemic	4
45	EUSZWALAU2021.00769	LAURACEAE	*Eusideroxylon zwageri* Teijsm. & Binn	Tambulian	Tree	OTS	VU	Native	2
46	FLUFLEPHY2021.00495	PHYLLANTHACEAE	*Flueggea flexuosa* Müll.Arg.	Anislag	Tree	OTS	LC	Native	1
47	GLEPHISAP2021.00591	SAPINDACEAE	*Glenniea philippinensis* (Radlk.) Leenh.	Mamoko	Tree	VU	NE	Native	1
48	GLOPATSAP2021.00501	SAPINDACEAE	*Gloeocarpus patentivalvis* (Radlk.) Radlk.	Tamaho	Tree	EN	NT	Endemic	1
49	GOMPSISTE2021.00523	STEMONURACEAE	*Gomphandra psilandra* Schori	Gomphandra	Tree	EN	EN	Endemic	1
50	GRAMULORC2021.00488	ORCHIDACEAE	*Grammatophyllum multiflorum* Lindl.	Rosa mia	Orchid	VU	NE	Endemic	1
51	GRASPEORC2021.00756	ORCHIDACEAE	*Grammatophyllum speciosum* Blume	Comely marked orchid	Orchid	CR	NE	Native	1
52	GYMNOBCAS2020.00427	CASUARINACEAE	*Gymnostoma nobile* (Whitmore) L.A.S.Johnson	Palawan Agoho	Tree	VU	NE	Native	1

Table 1. (Con't)

No.	Accession code	Family*	Scientific name*	Common name	Plant Habit	Threat Category DAO 2017-11	Threat Category IUCN 2022-1	Endemicity**	N
53	HETCALARE2019.00384	ARECACEAE	*Heterospathe califrons* Fernando	Yanisi	Palm	CR	CR	Endemic	15
54	HETSCIARE2021.00482	ARECACEAE	*Heterospathe scitula* Fernando	Malasanakti	Palm	CR	EN	Endemic	21
55	HOPACUDIP2021.00759	DIPTEROCARPACEAE	*Hopea acuminata* Merr.	Manggachapui	Tree	EN	VU	Endemic	38
56	HOPMALDIP2019.00382	DIPTEROCARPACEAE	*Hopea malibato* Foxw.	Yakal kaliot	Tree	CR	VU	Endemic	95
57	HOPPHIDIP2021.00577	DIPTEROCARPACEAE	*Hopea philippinensis* Dyer	Gisok-gisok	Tree	CR	EN	Endemic	29
58	HOPPLADIP2019.00400	DIPTEROCARPACEAE	*Hopea plagata* (Blanco) S.Vidal	Saplungan	Tree	VU	CR	Native	95
59	HOPQUIDIP2021.00494	DIPTEROCARPACEAE	*Hopea quisumbingiana* H.G.Gut.	Quisumbing Gisok	Tree	CR	EN	Endemic	1
60	HYDALCACH2021.00484	ACHARIACEAE	*Hydnocarpus alcalae* C.DC.	Dudua	Tree	OTS	EN	Endemic	1
61	INTBIJFAB2021.00528	FABACEAE	*Intsia bijuga* (Colebr.) O.Ktze.	Ipil	Tree	VU	NT	Native	35
62	KOOPINANA2020.00465	ANACARDIACEAE	*Koordersiodendron pinnatum* (Blanco) Merr.	Amugis	Tree	OTS	NE	Native	96
63	LICSPIARE2020.00460	ARECACEAE	*Licuala spinosa* Wurmb.	Balatbat	Palm	VU	NE	Native	2
64	LITCHISAP2020.00452	SAPINDACEAE	*Litchi chinensis* Sonn. subsp. *philippinensis* (Radlk.) Leenh.	Alupag	Tree	VU	NE	Native	20
65	LITLEYLAU2021.00510	LAURACEAE	*Litsea leytensis* Merr.	Batikuling	Tree	EN	NT	Endemic	2
66	MADBETSAP2020.00466	SAPOTACEAE	*Madhuca betis* (Blanco) Macbr. & Merr.	Betis	Tree	EN	VU	Native	18
67	MANALTANA2019.00401	ANACARDIACEAE	*Mangifera altissima* Blanco	Pahutan	Tree	VU	DD	Endemic	1
68	MEDCUMMEL2021.00766	MELASTOMATACEAE	*Medinilla cumingii* Naudin	Cumingi	Epiphyte	VU	NE	Native	2
69	MEDMAGMEL2019.00410	MELASTOMATACEAE	*Medinilla magnifica* Lindl.	Kapa-kapa	Epiphyte	CR	NE	Native	11
70	MEDMINMEL2021.00760	MELASTOMATACEAE	*Medinilla miniata* Merr.	Miniata	Epiphyte	EN	NE	Endemic	2
71	MEDPENMEL2021.00545	MELASTOMATACEAE	*Medinilla pendula* Merr.	Baladu	Epiphyte	EN	NE	Endemic	5
72	MITLANANN2021.00507	ANNONACEAE	*Mitrephora lanotan* (Blanco) Merr.	Lanutan	Tree	OTS	NT	Endemic	10
73	MYRPHIMYR2021.00522	MYRISTICACEAE	*Myristica philippensis* Lam.	Duguan	Tree	OTS	LC	Endemic	20
74	NAGWALPOD2021.00771	PODOCARPACEAE	*Nageia wallichiana* (C.Presl) Kuntze	Malaalmaciga	Tree	OTS	LC	Native	1
75	NEPRAMSAP2019.00411	SAPINDACEAE	*Nephelium ramboutan-ake* (Labill.) Leenh.	Kapulasan	Tree	VU	NE	Native	6
76	ONCPLAARE2021.00540	ARECACEAE	*Oncosperma platyphyllum* Becc.	Anibong	Palm	EN	CR	Endemic	1
77	PALLUZSAP2020.00454	SAPOTACEAE	*Palaquium luzoniense* (F. Vill.) S.Vidal	Red Nato	Tree	VU	VU	Native	4
78	PALPHISAP2021.00557	SAPOTACEAE	*Palaquium philippense* (Perr.) C.B.Rob.	Malak-malak	Tree	VU	LC	Endemic	9
79	PHAAPHORC2020.00463	ORCHIDACEAE	*Phalaenopsis amabilis* (L.) Blume	Mariposa	Orchid	EN	NE	Native	1

Table 1. (Con't)

No.	Accession code	Family*	Scientific name	Common name	Plant Habit	Threat Category		Endemicity**	N
						DAO 2017-11	IUCN 2022-1		
80	PHAAPHORC2020.00463	ORCHIDACEAE	*Phalaenopsis aphrodite* Rchb.f.	Mariposa	Orchid	VU	NE	Native	1
81	PHASCHORC2020.00464	ORCHIDACEAE	*Phalaenopsis schilleriana* Rchb. f.	Tiger orchid	Orchid	EN	NE	Endemic	2
82	PHOLOUARE2020.00439	ARECACEAE	*Phoenix loureiroi* Kunth.	Voyavoi Palm	Palm	OTS	LC	Native	1
83	PINBICARE2021.00570	ARECACEAE	*Pinanga bicolana* Fernando	Bicol abiki	Palm	CR	CR	Endemic	25
84	PLAVILSAP2021.00519	SAPOTACEAE	*Planchonella villamilii* (Merr.) Swenson	Villamil Nato	Tree	VU	EN	Endemic	1
85	PODCOSPOD2019.00446	PODOCARPACEAE	*Podocarpus costalis* C.Presl	Igem dagat	Tree	EN	EN	Native	1
86	PREODOLAM2021.00768	LAMIACEAE	*Premna odorata* Blanco	Alagau	Tree	OTS	LC	Native	1
87	KINALTFAB2019.00444	FABACEAE	*Prioria alternifolia* (Elmer) Breteler	Batete	Tree	VU	VU	Native	2
88	PTEINDFAB2020.00476	FABACEAE	*Pterocarpus indicus* Willd. forma *echinatus* (Pers.) Rojo	Prickly Narra	Tree	VU	EN	Native	66
89	PTEINDFAB2020.00475	FABACEAE	*Pterocarpus indicus* Willd. forma *indicus*	Smooth Narra	Tree	VU	EN	Naturalized	86
90	RADCORBIG2020.00426	BIGNONIACEAE	*Radermachera coriacea* Merr.	Labayanan	Tree	VU	EN	Endemic	1
91	REUTRIEIP2020.00456	EUPHORBIACEAE	*Reutealis trisperma* (Blanco) Airy Shaw	Baguilumbang	Tree	VU	VU	Endemic	5
92	SARROTARE2020.00474	ARECACEAE	*Saribus rotundifolius* (Lam.) Blume	Anahau	Palm	OTS	NE	Native	31
93	SHOALMDIP2020.00461	DIPTEROCARPACEAE	*Shorea almon* Foxw.	Almon	Tree	VU	NT	Native	2
94	SHOASTDIP2021.00538	DIPTEROCARPACEAE	*Shorea astylosa* Foxw.	Yakal	Tree	CR	EN	Endemic	1
95	SHOCONDIP2019.00396	DIPTEROCARPACEAE	*Shorea contorta* S.Vidal	White Lauan	Tree	VU	LC	Native	387
96	SHONEGDIP2020.00445	DIPTEROCARPACEAE	*Shorea negrosensis* Foxw	Red Lauan	Tree	VU	LC	Native	3
97	SHOPOLDIP2021.00762	DIPTEROCARPACEAE	*Shorea polysperma* (Blanco) Merr.	Tanguile	Tree	VU	LC	Endemic	19
98	SINSUPFAB2019.00403	FABACEAE	*Sindora supa* Merr.	Supa	Tree	EN	VU	Endemic	2
99	STRMACFAB2020.00469	FABACEAE	*Strongylodon macrobotrys* A. Gray	Jade vine	Vine	EN	NE	Endemic	5
100	SYMDENFAB2021.00590	FABACEAE	*Sympetalandra densiflora* (Elmer) Steenis	Kamatog	Tree	EN	NT	Endemic	1
101	SYZNITMYR2021.00488	MYRTACEAE	*Syzygium nitidum* Benth.	Makaasim	Tree	VU	LC	Native	6
102	TECPHILAM2021.00468	LAMIACEAE	*Tectona philippinensis* Benth. & Hook.	Philippine Teak	Tree	EN	EN	Endemic	7
103	TOOCALMEL2021.00458	MELIACEAE	*Toona calantas* Merr. & Rolfe	Kalantas	Tree	VU	DD	Native	8
104	TRIDECMYR2021.00502	MYRTACEAE	*Tristaniopsis decorticata* (Merr.) Peter G.Wilson & J.T.Waterh.	Malabayabas	Tree	VU	LC	Endemic	1

Table 1. (Con't)

No.	Accession code	Family*	Scientific name	Common name	Plant Habit	Threat Category DAO 2017-11	Threat Category IUCN 2022-1	Endemicity**	N
105	VANSANORC2021.00757	ORCHIDACEAE	*Vanda sanderiana* Rchb.f.	Waling-waling	Orchid	CR	NE	Endemic	5
106	VATMANDIP2021.00537	DIPTEROCARPACEAE	*Vatica mangachapoi* Blanco ssp. *mangachapoi*	Narig	Tree	VU	VU	Native	1
107	VITPARLAM2019.00408	LAMIACEAE	*Vitex parviflora* Juss.	Molave	Tree	EN	LC	Native	130
108	WALCELFAB2020.00453	FABACEAE	*Wallaceodendron celebicum* Koord.	Banuyo	Tree	VU	NE	Native	22
109	XANVERMYR2020.00496	MYRTACEAE	*Xanthostemon verdugonianus* Naves	Mangkono	Tree	EN	VU	Native	1
110	ZIZTALRHA2021.00772	RHAMNACEAE	*Ziziphus talanai* (Blanco) Merr.	Balakat	Tree	OTS	VU	Endemic	13
			Total						2136

CONCLUSIONS AND RECOMMENDATIONS

The threatened plants in the Makiling Botanic Gardens represent only 11% of 984 species in the threatened plant list. This gives MBG its first initial list of documented threatened species. There is a need to prioritize these species for national and global conservation and restoration in response to PBSAP and GSPC targets. Long-term programs on conservation and restoration must be developed, which may include regular assessment of threatened plants; the establishment of long-term ecological research plots; conservation biology of selected threatened species; biodiversity education and advocacy; other significant programs that will entail regular monitoring; and updating the conservation status of other important native and endemic species in MBG. The study recommends further conducting an inventory to cover a larger area and possibly more threatened species.

ACKNOWLEDGMENT

The authors would like to thank the Department of Science and Technology (DOST) for their funding support for the project.

LITERATURE CITED

Amoroso, V. B., Amoroso, C. B., & F. P. Coritico. (2012). Diversity and status of plants in three mountain ecosystems in Southern Mindanao, Philippines. *Asian Journal of Biodiversity*, *3*(83), 50–73.

Ariati, S. R. & Widyatmoko, D. (2019). Botanic garden profile. Bogor Botanic Gardens. *SIBBALDIA: The Journal of Botanic Garden Horticulture*, *17*.

Bantayan, N. C., Abraham, E. R. G., & Fernando, E. S. (2008). Geodatabase development for forest restoration and biodiversity conservation in the Mt. Makiling Forest Reserve, Philippines. *The Philippine Agricultural Scientist*, *91*(4), 365–371.

BGCI [Botanic Gardens Conservation International]. (u.d). Bogor Botanic Gardens (Center for Plant Conservation-Botanic Gardens). Retrieved on 09 December, 2022 from: <https://tools.bgci.org/garden.php?id=39&ftrCountry=All&ftrKeyword=Bogor+Botanic+Gardens&ftrBGCImem=&ftrIAReg=>.

Brown, W. H. (1919). The vegetation of Philippine Mountains. *Bureau of Science Publication* No. 13, Manila, 434 p.

Castillo, L. A., Bantayan, N. C., Canceran, M. S., Barua, L. D., Alegre, A. C., Gonzalvo, K. J. P., Gestiada, E. C., Parducho, V. B., Limpiada, A. L., &. Castillo, M. L. (2021). Tree composition, diversity, and stand structure of mid-montane forest in Sipit watershed, Mount Makiling Forest Reserve ASEAN Heritage Park, Philippines. P*hilippine Journal of Science*, *150 (S1) Special Issue on Philippine Biodiversity Conservation*, 257–269.

Castillo, M. L., Castillo, L. A., Canceran, M. S., Gonzalvo, K. J. P., Barua, L. D., Alegre, A. C., Barredo-Parducho, V. O., Gestiada, E. C., Breva, R. V., & Bantayan, N. C. (2018). Distribution, diversity and spatial analysis of tree species in a long-term ecological research plot in Molawin-Dampalit Watershed, Mount Makiling Forest Reserve. *Asian Journal of Biodiversity*, *9*(1), 12–36.

CBD [Convention on Biological Diversity]. (2012). Global Strategy for Plant Conservation: 2011-2020 Botanic Gardens Conservation International, Richmond. UK.

DENR-BMB [Department of Environment and Natural Resources – Biodiversity Management Bureau]. (2016). Philippine Biodiversity Strategy and Action Plan 2015-2028. Bringing resilience to Filipino Communities. 239 p. Retrieved from: < https://www.cbd.int/doc/world/ph/ph-nbsap-v3-en.pdf>.

DENR-DAO. [Department of Environment and Natural Resources Administrative Order]. (2017). Updated National List of Threatened Philippine Plants and their Categories. 30 p.

DENR-DAO. [Department of Environment and Natural Resources Administrative Order]. (2011). National List of Threatened Philippine Plants and their Categories, and the List of Other Wildlife Species.

Edgar, G. J., Langhammer, P. F., Allen, G., Brooks, T. M., Brodie, J., Crosse, W., De Silva, N., Fishpool, L. D. C., Foster, M. N., Knox, D. H., Mccosker, J. E., Mcmanus, R., Millar, A. J. K., & Mugo, R. (2008). Key biodiversity areas as globally significant target sites for conservation of marine biological diversity. *Aquatic Conservation Marine and Freshwater Ecosystems*, *18*(6), 969–983.

Fernando, E. S., Sun, B. Y., Suh, M. H., Kong, H. Y., & Koh, K. S. (2004). Flowering Plants and Ferns of Mt. Makiling. ASEAN-Korea Environmental Cooperation Unit, Seoul National University, Korea. ISBN 89-955147-1-X 96480, 368 p.

Gruezo, W. Sm. (1997). Flora diversity profile of Mt. Makiling Forest Reserve, Luzon, Philippines. *In: The Conditions of Biodiversity Maintenance in Asia*. East-West Center USA. pp. 53–202.

Lapitan, P. G., Fernando, E. S., Suh, M. H., Fuentes, R. U., Shin, Y. J., Pampolina, N. M., Castillo, M. L., Cereno, R. P., Lee, J. H., Han, S., Choi, T.B., & Lee, D. K. (2010). *Biodiversity and Natural Resources Conservation in Protected Areas of Korea and the Philippines*. ASEAN-Korea Environmental Cooperation Unit (AKECU), National Instrumentation Center for Environmental Management, College of Agriculture and Life Sciences, Seoul National University, Korea.

Nanakorn, W. & Indharamusika, S. (1997). Ex-situ conservation of native Thai orchids at Queen Sirikit Botanic Garden. Lecture presented at the International Conference on Biodiversity and Bioresources: Conservation and Utilization, 23–27 November 1997, Phuket, Thailand. Retrieved from: <http://www.iupac.org/symposia/proceedings/phuket97/nanakorn.html>.

Pancho, J. V. (1983). Vascular flora of Mt. Makiling and vicinity (Luzon: Philippines), Part 1. Kalikasan, *Philippine Journal of Biology Supplement No. 1*. New Mercury Printing Press, Quezon City.

Villanueva, E. L. C. & Buo, I. E. (2015). Threatened plant species of Mindoro, Philippines. *IAMURE International Journal of Ecology and Conservation*. http//dx.doi.org/10.778/ijec.v14I1.901

Yam, T. W., Tay, F., Ang, P., & J. Chua. (2010). *Ex situ* orchid conservation – A case study from the Singapore Botanic Gardens. *Acta Horticulturae*, *878*, 21–28.

p-ISSN 2012-3612 │ e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 │ Number 1 │ pp. 82–101│ 2023

A systematic review of the effects of elevated CO_2 concentration on the growth of selected tropical trees

John Karlo C. Saddoy[1*]

[1]*Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. The elevated CO_2 concentration causes drastic changes in the world's climatic conditions, affecting the growth and development of plants in their natural settings. Hence, scientists have been exploring this field to understand better the current trend of plant responses toward the intervention of elevated CO_2, and this systematic review created a generalized body of knowledge. The 27 out of 3,568 articles that passed the final selection process were selected and evaluated following the inclusion or exclusion Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The Population-Intervention-Comparison-Outcome (PICO) model was used to create Boolean search strings for the ScienceDirect and Scopus databases to find these included articles and Google Scholar for manual searching. These articles were downloaded as BibTeX and organized on Mendeley (version 1.19.8). The QGIS (version 3.16.15) was used to create the world map, and RStudio (version 4.2.2) was also used to visualize the descriptive statistics. The results showed that India (9 articles) has the highest number of reviewed articles, followed by the Republic of Panama and Brazil (4 articles each), Malaysia (3 articles), China and England (2 articles each), and Portugal, Australia, and Borneo (1 article each). Twenty-four articles had a controlled methodological approach, while three had an observational approach. The reviewed articles revealed that the elevated CO_2 affected the biomass (aboveground, belowground, dry, and total plant biomass) production, morphological (leaf characteristics, root characteristics, number of branches, stomatal characteristics, plant height, and stem diameter), and physiological (photosynthetic rates, transpiration rates, water use efficiency, stomatal conductance, intercellular CO_2 concentration, chlorophyll content, and biochemical activity) response of the tropical trees. Hence, it is justified that there are tropical tree species that can and cannot survive the worsening climate change.

Keywords: Review article, PRISMA protocol, Boolean search string, Climate change

Article Information
Received 19 January 2023
Accepted 26 May 2023
Published online 16 October 2023
*Email: jcsaddoy@up.edu.ph

INTRODUCTION

For over three decades, the world has been struggling against the adverse impacts of climate change, especially in tropical regions (Tang, 2019). Global warming is one of its effects, as scientists predicted a sudden increase in temperature by 2-5°C in 2100 (IPCC, 2013). Anthropogenic activities concerning greenhouse gas emissions (CO_2, N_2O, and CH_4) are the leading factor of global warming, associated with burning fossil fuels in developed countries such as China, the United States of America, and parts of Europe (Lacis *et al.*, 2013; Corlett, 2018). Specifically, the latest data on the CO_2 concentration in the atmosphere as of March 2021 has risen to 417 M ppm, considered the highest data for the past 800,000 years (Lindsey, 2007; Betts, 2021). Seeing this trend, it is interesting to determine how plants respond morphologically and physiologically to this emerging problem.

From the start of the 21st century, several scientific papers revealed that elevated CO_2 improves plant growth, leaf area, water use efficiency, and photosynthesis (Lovelock *et al.*, 1999; Khurana & Singh, 2001; Leakey *et al.*, 2002). After a decade, this topic has gained much attention as published studies have been emerging to broaden the understanding of the effects of elevated CO_2 concentration on plant growth, development, and other physiological activities (Janani *et al.*, 2016;

Singh *et al.*, 2019). Recent literature concluded that the rising atmospheric CO_2 also increased the production of biomass, leaf-level productivity, water efficiency, and plant C/N uptake (Needham *et al.*, 2020; Avila *et al.*, 2020; Rai *et al.*, 2020; Reichgelt *et al.*, 2020). Thus, both past and present literature show that the elevated CO_2 concentration has a significant relationship with plant growth, making it still relevant today.

However, there were studies in the same field that revealed alternative results. They found that elevated CO_2 did not significantly correlate with root growth, photosynthates, photosynthetic rates, plant height, and the number of leaves (Warrier *et al.*, 2013; Musa *et al.*, 2017; Tietze *et al.*, 2019). Thus, it is also a manifested notion that there is still needs to be a more specific understanding of this field of study. There are also limited reviews regarding the effects of the elevated CO_2 concentration on the growth of selected tropical trees, especially from 2010 to 2021, when drastic changes in CO_2 concentration in the atmosphere were observed (Betts, 2021). Most of the published meta-analyses about elevated CO_2 included other environmental factors, such as water stress and temperature, and discussed the broader scope of forest ecophysiology (Curtis & Wang, 1998; Kallarackal & Roby, 2012; Wang *et al.*, 2012; Cernusak *et al.*, 2013). Thus, it is necessary to have a comprehensive review of published papers concerning the topic at a finer scale, which can be used to distinguish the research gaps for future research.

The use of the Population-Intervention-Comparison-Outcome (PICO) model leads to credible and clarified answers because it shows the logical pathways of action needed, which helps the researchers to visualize the experiments conducted for the benefit of the population (Miller & Forrest, 2001; Booth *et al.*, 2019; Skivington *et al.*, 2021). This systematic review aids in the creation of the Boolean strings to target the needed articles for the results. On the other hand, the PRISMA protocol is used to understand the necessity for the review, reporting the findings of various authors and the results they achieved (Page *et al.*, 2021). Hence, applying the PRISMA protocol, the PICO model, and the Boolean search string to other fields of science, especially forestry, aside from medical science, creates an opportunity to conduct more systematic reviews and a firm understanding of various topics.

This study aims to summarize through a systematic review the effects of the elevated CO_2 concentration on the growth of selected tropical trees within the 2010-2021 period in which drastic changes in the climate have been recorded. This study will also discuss the relationship between the elevated CO_2 concentration and the growth of tropical trees; distinguish the research gaps, especially in the Philippine context; and develop recommendations for the future progress of the research field.

METHODOLOGY

Research question

This systematic review addressed the primary question: "What are the effects of the elevated CO_2 concentration on the biomass, morphological growth, and physiological response of the selected tropical trees?" Adapting the protocol for an environmental PICO model in a systematic review of Livoreil *et al.* (2017), the research question was formulated as shown in **Table 1**.

Table 1. The research question of the systematic review using PICO.

Definitio	Description of the study
Population	Selected tropical trees
Intervention	Elevated CO_2 concentration
Comparison	Control/No treatment
Outcome	Effects on the biomass, morphological growth, and physiological response of the tropical trees
Question	What are the effects of the elevated CO_2 concentration on the biomass, morphological growth, and physiological response of the selected tropical trees?

Eligibility criteria

This systematic review was embedded in the PRISMA protocol based on Page *et al.* (2021). The final set of research articles included in this review was based on Figure 1 concerning the inclusion or exclusion criteria. The title-abstract-keyword advanced search strategy was utilized to identify the relevant research articles for the systematic review, implying that the match words should be in the pool of keywords in the search string. The research articles were the only document type needed for this systematic review. Other document types, such as conference papers, reviews, book chapters, books, notes, editorials, short surveys, and erratum were excluded. The publication period was from 2010 to 2021. The preferred language for article selection was English. In the ScienceDirect database (https://www.sciencedirect.com/), the included research articles were found in the open access and open archive, and the subject area should be 'environmental science.' Other subject areas unrelated to forestry or any field of environmental science were excluded as these may cause misleading results that lead to inappropriate conclusions.

Figure 1. The inclusion or exclusion criteria based on the PRISMA protocol in Page *et al.* (2021).

Secondly, titles and abstracts of the compiled set of articles were further screened. The title must be compatible with the inclusion/exclusion criteria, with the relevant keywords used in the search query. Each research article is different because of the title and publication year. Otherwise, such research papers were excluded. In this stage, abstract screening was necessary to verify and validate the credibility of the remaining research articles. The article was only included if the abstract was relevant to the research question and the criteria presented below.

If the abstract clearly presents the methodology and result of the study, the last part of the screening process will push through. The full-text screening strategy was implemented for all the remaining research articles to examine the credibility of the methodology, and their presented results were inclined with the criteria and research question. Moreover, the screened research articles were derived from the ScienceDirect database under open access for full-text screening and in the Scopus database. They were exported to Mendeley (version 1.19.8) for proper organization. If the screened research articles were unavailable in the database, manual searching in any search engine, such as Google, was used to access the PDF file of the article.

Search strategy and selection process

The primary method for finding research articles needed for this systematic review was using Boolean operators and their principles based on Aliyu (2017). These search strings were anchored in the PICO model. In the search strings, the use of AND, OR, and quotation marks (" ") in the advanced search bar in the research database were maximized to target the research article directly for this systematic review. To address the limitation of ScienceDirect when using a Boolean search string, **Table 2** presents five (5) Boolean search strings to cover all the necessary research articles for this systematic review. In addition, the Scopus database has no restrictions for the Boolean connectors per field. Lastly, **Figure 2** summarizes the five-step procedure for finding the final articles to be reviewed for selection.

Table 2. The research question of the systematic review using PICO.

Number	Search string
1	"Elevated CO_2" OR "Increased CO_2" OR "CO_2 enrichment" OR "atmospheric CO_2" AND "ppm" AND "Growth response" OR "Growth" AND "Tropical Forest Tree" OR "Tropical Tree"
2	"Elevated atmospheric CO_2" OR "Increased CO_2" OR "CO_2 enrichment" AND "Morphology" OR "Morphological response" OR "Morphological parameters" AND "Tropical Forest Tree" OR "Tropical Tree"
3	"Elevated atmospheric CO_2" OR "Increased CO_2" OR "CO_2 enrichment" AND "ppm" AND "Physiology" OR "Physiological response" OR "Physiological parameters" AND "Tropical Forest Tree" OR "Tropical Tree"
4	"Elevated atmospheric CO_2" OR "CO_2 enrichment" OR "Increased Air CO_2" AND "Plant height" OR "Root length" OR "Plant biomass" OR "Leaf length" AND "Tropical Tree" OR "Tropical Forest Tree"
5	"Elevated atmospheric CO_2" OR "CO_2 enrichment" OR "Increased Air CO_2" AND "Photosynthesis" OR "Transpiration" OR "Stomatal Conductance" OR "Respiration" AND "Tropical Tree" OR "Tropical Forest Tree"

Data collection

The information sources of this systematic review included ScienceDirect and Scopus. The required articles for this systematic review were scanned and reviewed using the eligibility criteria in **Figure 1** and the selection process in **Figure 2**. The BibTeX file exported the articles from each Boolean search string. The downloaded BibTeX files will be uploaded to Mendeley (version 1.19.8) because it has a built-up mechanism to eliminate identical research papers. A manual search of relevant articles using a Boolean search string was done in ScienceDirect and Scopus (**Table 3**). **Figure 3** summarizes the combination of the mentioned databases and manual searching using Google Scholar, following the method by Hernandez *et al.* (2020) called chain searching. As mentioned in the eligibility criteria, other papers except research articles were excluded even in chain searching to ensure the consistency of the data. Hence, grey literature from the government, intergovernmental agencies, and non-governmental organizations was also excluded.

Data categorization

Articles were categorized based on the treatments of CO_2 being applied to the selected tropical tree species. The first category focused on ambient and elevated CO_2 concentrations. The 27 articles had different ranges of ambient levels of CO_2 by which a certain CO_2 level could be an ambient level in one study but could also be elevated in another study. Thus, using ambient (300–532 ppm) and elevated CO_2 (460–910 ppm) in this systematic review is justifiable. The experiment duration is another category knowing that the exposure

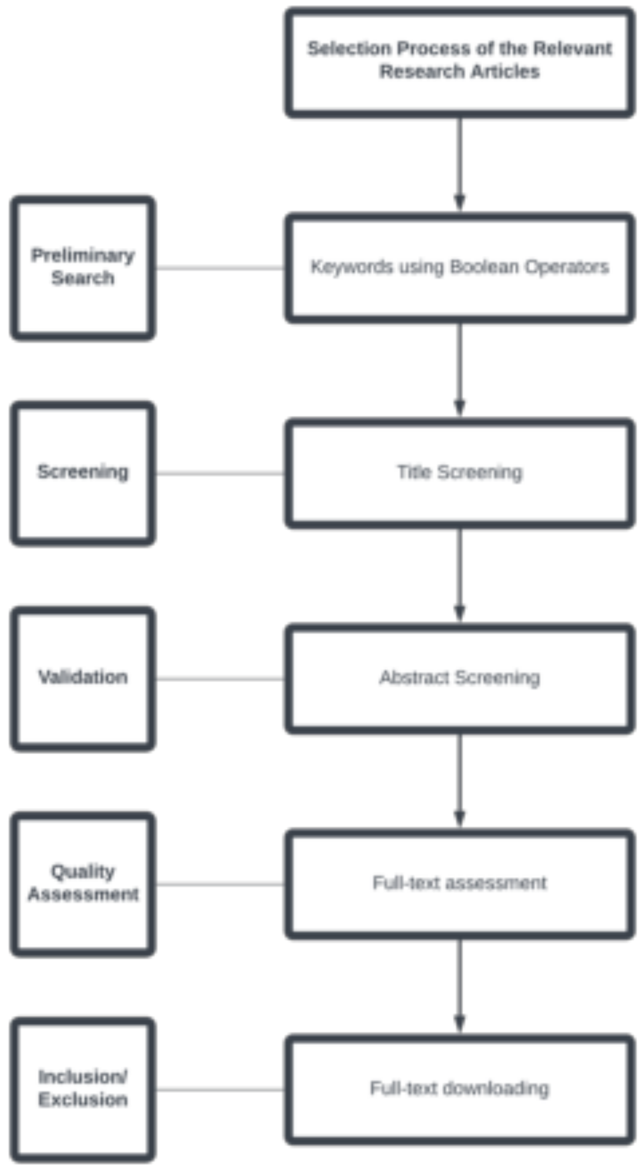


Figure 2. Step-by-step procedure of selection process based on PRISMA.

Table 3. The number of articles emerged using the search strings.

No.	Search string	No. of articles		Total
		ScienceDirect	Scopus	
1	"Elevated CO_2" OR "Increased CO_2" OR "CO_2 enrichment" OR "atmospheric CO_2" AND "ppm" AND "Growth response" OR "Growth" AND "Tropical Forest Tree" OR "Tropical Tree"	175	15	190
2	"Elevated atmospheric CO_2" OR "Increased CO_2" OR "CO_2 enrichment" AND "Morphology" OR "Morphological response" OR "Morphological parameters" AND "Tropical Forest Tree" OR "Tropical Tree"	182	9	191
3	"Elevated atmospheric CO_2" OR "Increased CO_2" OR "CO_2 enrichment" AND "ppm" AND "Physiology" OR "Physiological response" OR "Physiological parameters" AND "Tropical Forest Tree" OR "Tropical Tree"	749	6	755
4	"Elevated atmospheric CO_2" OR "CO_2 enrichment" OR "Increased Air CO_2" AND "Plant height" OR "Root length" OR "Plant biomass" OR "Leaf length" AND "Tropical Tree" OR "Tropical Forest Tree"	1,125	12	1,137
5	"Elevated atmospheric CO_2" OR "CO_2 enrichment" OR "Increased Air CO_2" AND "Photosynthesis" OR "Transpiration" OR "Stomatal Conductance" OR "Respiration" AND "Tropical Tree" OR "Tropical Forest Tree"	1,230	45	1,275
	TOTAL			3,548

duration of plants to elevated CO_2 can produce different results (Mndela *et al.*, 2022). Studies done in less than a year were considered short-term exposure, whereas those done in more than a year were regarded as long-term exposure. The articles were further divided into two subcategories based on their methodological approach: observational and controlled experiments. The observational approach included studies in the natural environment where elevated CO_2 exists. The controlled approach included studies highlighting a greenhouse, glasshouse, laboratory, or aided equipment to elevate the CO_2 within the area.

Data analysis and presentation

Microsoft Excel was used to organize the collected data for this systematic review. RStudio (version 4.2.2) was also utilized to visualize the descriptive statistics (*i.e.*, mean, range, counts, and percentages) for the identified categories and subcategories to homogenize the data. Multiple spell checks were done for each input under every category to minimize the doubling counting and error. Percentages were identified in terms of the number of chosen articles or the number of articles associated with each category and subcategory. Map layout was done in QGIS 3.16.15 software to plot the distribution of the reviewed research article.

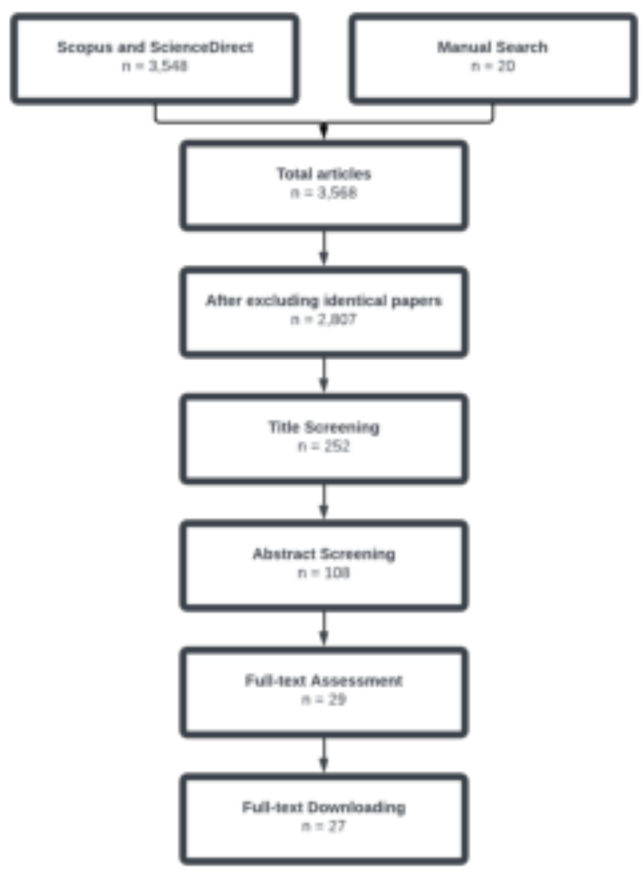


Figure 3. Flow diagram of the result of the screening processes.

RESULTS

Study characteristics and approaches

Applying the inclusion or exclusion criteria based on the PRISMA protocol, 761 out of 3,568 were found as identical research articles. Titles of the articles were then examined, wherein only 108 remained after the screening. Then, 29 articles were retained after assessing abstracts (*i.e.*, a proper account of methodology and results). Only 27 articles were subject to data homogenization and analysis, as two were outside the open access or archive category.

Fifteen of 27 articles were published in Asia (India, China, Borneo, and Malaysia), as shown in **Figure 4**. Published papers in Portugal, England, and Australia used tropical species, making them relevant to this review. Specifically, India has the highest number of reviewed studies, followed by Brazil and the Republic of Panama (**Figure 5**). Conversely, the countries with the least reviewed studies were Portugal, Borneo, and Australia. Interestingly, no research papers were found from the Philippines and other developing countries in Southeast Asia. Twenty-four articles that passed the final selection process had a controlled methodology wherein the tropical tree species were exposed to the manipulated CO_2 concentration using chambers, glasshouses, and greenhouses. Three articles followed observational methodology; hence, these studies used Free-Air CO_2 Enrichment (FACE) method, where plants were exposed to elevated CO_2 in their natural settings. Replications were done in every study to ensure the credibility of the results.

In the case of the publication year of reviewed articles, 2021 had the highest number of published articles (6), followed by 2013 and 2019 (4; **Figure 6**). No published papers were included in 2010, 2012, 2017, and 2020 as reviewed articles in these years were focused on weeds, crops, and ornamental plants in temperate regions.

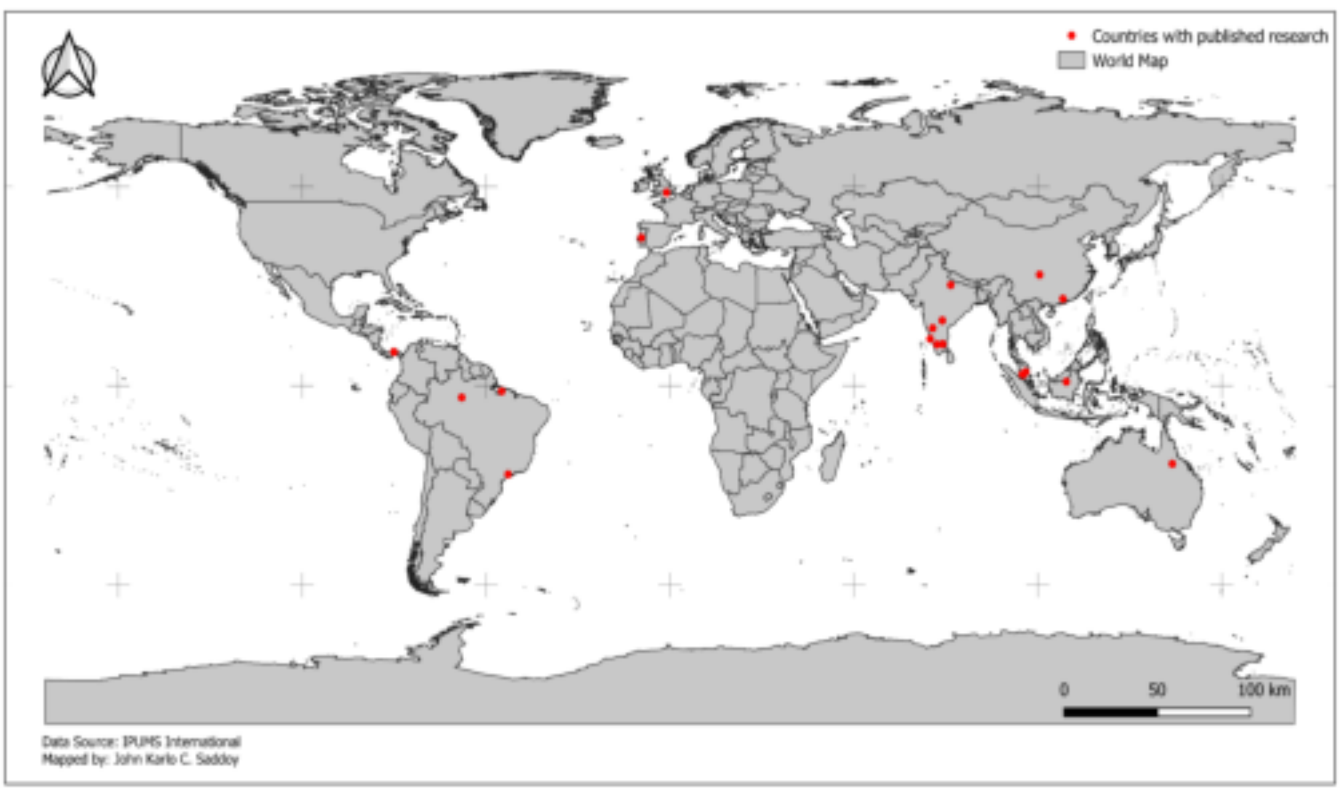


Figure 4. Geographical map distribution of the studies about the effects of elevated CO_2 on the growth of tropical trees with the bar plot of study approaches.

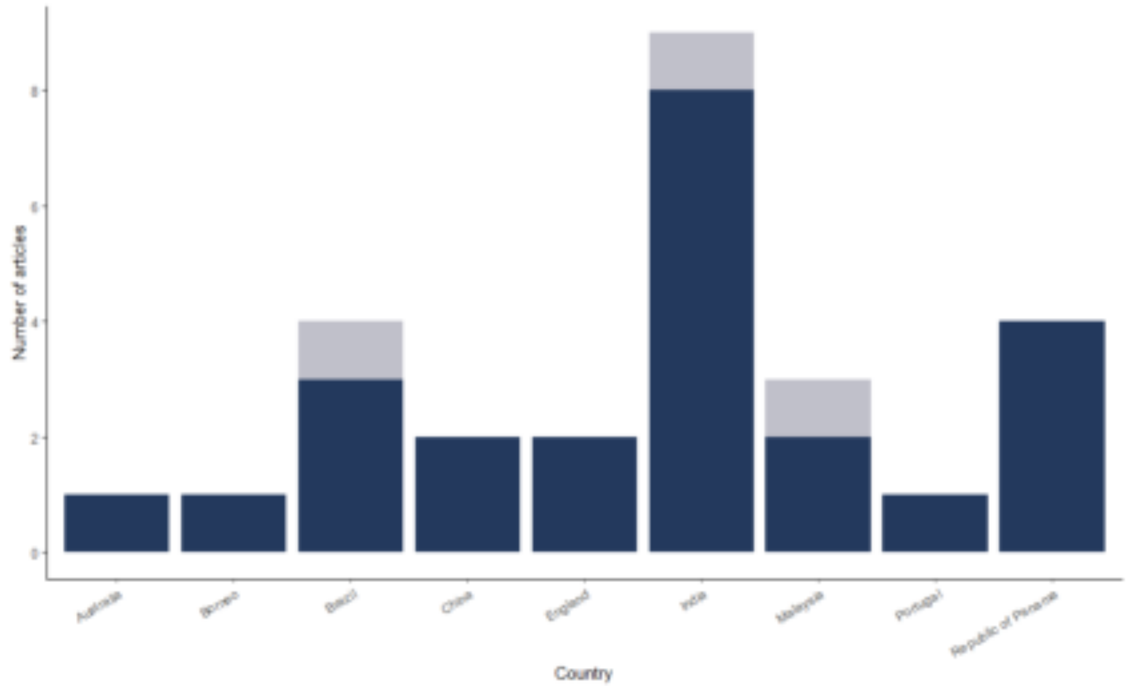


Figure 5. The number of articles per country and their corresponding methodological approaches.

Study duration

The mean and mode of the study duration among reviewed articles are 5.43 months and 3 months, respectively. Study duration ranged from 1 month to 60 months. Twenty out of 27 articles employed short-term exposure to the elevated CO_2 on the growth of the tropical tree species (**Figure 7**).

Life stages of the species used in the study

The species mentioned in the reviewed articles were categorized into seedlings, saplings, and trees (**Figure 8**). While five studies did not state the specific life stages of plants, the age, diameter, and height were nonetheless described, which allowed further categorization. About 59.26% of the total reviewed papers used seedlings in their study, 29.63% of papers used saplings, and the mature trees were the least life stages of the species used with 11.11%.

Biological parameters for analyses

The biomass (aboveground and belowground biomass, dry biomass, and total plant biomass), morphological characteristics, and physiological response were included to analyze the overall growth of study species (**Table 4**). Morphological parameters were leaf characteristics (leaf area, leaf number, N and P leaf concentration), root characteristics (root weight and root length), number of branches, stomatal characteristics (stomatal density and stomatal size), plant height, and plant diameter. Physiological parameters included photosynthetic rates, transpiration rates, water use efficiency, stomatal conductance, intercellular CO_2 concentration, chlorophyll content, and biochemical activity (Rubisco activity and photosynthetic enzymes activity).

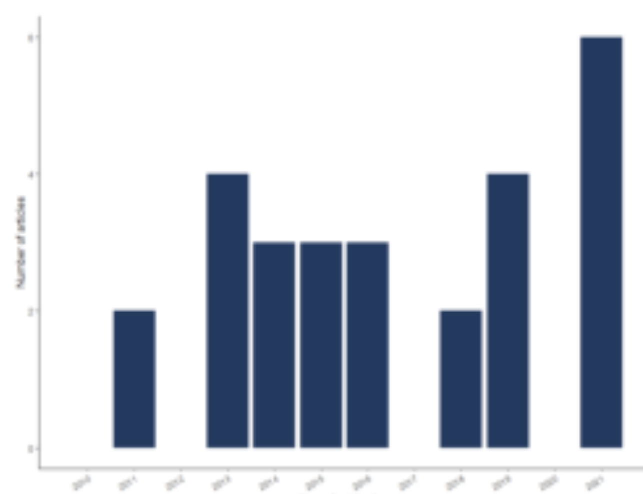


Figure 6. The number of articles per year of publication.

DISCUSSION

Positive response of the forest tree species under elevated CO_2

Increased production

Generally, the trend of biomass is directly related to the trend of CO_2 concentration. Warrier *et al.* (2013) agreed that the increased root biomass over low shoot biomass accounted for better adaptability of the species to the CO_2 concentration, while the increased shoot biomass is associated with the overall growth pattern of the species. The increased aerial and total plant biomass justified the narrative that *Gmelina arborea* Roxb. can accumulate more carbon (Rasineni & Reddy, 2013; Rasineni *et al.*, 2013). The increasing biomass trend in the tropical tree species used by Yan *et al.* (2014) was due to the increased mean annual net primary production. The increased leaf and root biomass were explained by the high physiological plasticity, which can adapt to various environments and has a greater capability for starch storage because of the utilization of transitory starch accumulation as a mechanism for carbon sink (Arenque *et al.*, 2014). This trend could be accounted for by the development of new carbon sinks in the plant system that can also explain the increasing morphological features of the plants and better utilization of photosynthates, which was revealed in the study of Sekhar *et al.* (2015). Hence, the species they used also had high morphological plasticity by which they could adjust to the new challenges offered by the environment. Other notable species with increased biomass production under the influence of elevated CO_2 were presented in **Table 5**.

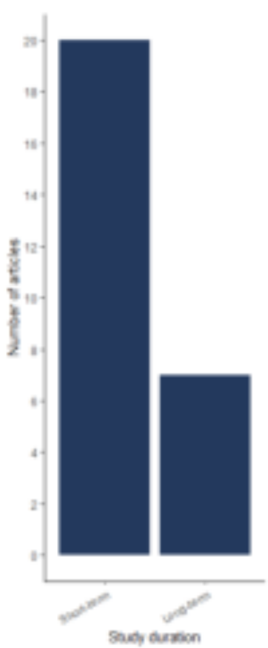


Figure 7. The number of articles per country and their corresponding methodological approaches.

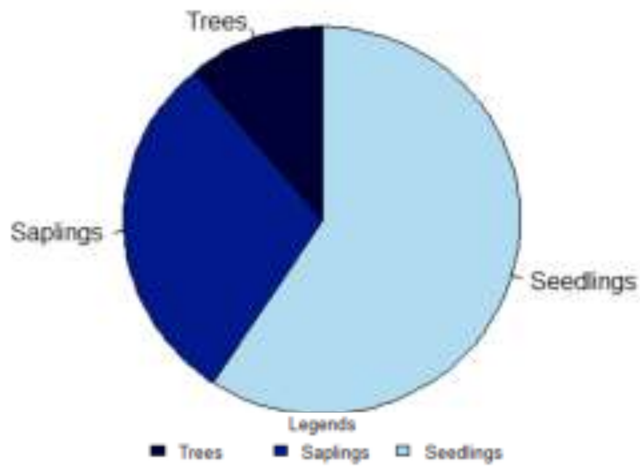


Figure 8. Life stages of the species used in the study.

Table 4. Growth parameters used in the study.

Biomass	Morphological parameter	Physiological parameter
Aboveground biomass	Leaf characteristics	Photosynthetic rates
Belowground biomass	Root characteristics	Transpiration rates
Dry biomass	Number of branches	Water use efficienc
Total plant biomass	Stomatal characteristics	Stomatal conductance
	Plant height	Intercellular CO_2 concentration
	Stem diameter	Chlorophyll content
		Biochemical activity

Increased morphological growth

Increased leaf area increased carboxylation efficiency using phosphoglyceric acid as the indicator and increased CO_2 assimilation (Bassham, 2003; Lamani *et al.*, 2016). Vogado *et al.* (2022) reported that the increased leaf area had a log-linear relationship with chlorophyll content and water-use efficiency. Conversely, the leaf number had increased under elevated CO_2 in the species presented in **Table 5.** These phenomena were due to species' expanding carbon sink and utilization of photosynthesis products, an adaptive mechanism for maximizing photosynthetic ability, increasing starch storage, and fresh and dry aboveground biomass production (Farquhar & Sharkey, 1982; Kumar *et al.*, 2014; Sekhar *et al.*, 2015; Lahive *et al.*, 2018). Meanwhile, the increased root length under elevated CO_2 was attributed to root biomass increment connected with the better biomass allocation in the root system and the increasing soluble sugars, photosynthetic rates, and non-structural carbohydrates (Dickson *et al.*, 1998; Zak *et al.*, 2000; Janani *et al.*, 2016).

Most results claimed that plant height is directly related to elevated CO_2. The list of species presented in **Table 5** with a positive response in plant height had increased biomass and biomass allocation to the root and shoot system (Zhu *et al.*, 2016; Janani *et al.*, 2016; Lamani *et al.*, 2016; Shi *et al.*, 2021). Other authors hypothesized that the increased plant height was linked with better photosynthates utilization, increased phenolic substances, transpiration rates, and soluble sugar concentration (Onoda *et al.*, 2009; Ghasemzadeh *et al.*, 2010; Ghasemzadeh & Jaafar, 2011; Kumar *et al.*, 2014; Ghini *et al.*, 2015). Rasineni *et al.* (2013) claimed that an increase in plant height resulted in the sink's increased size, which further implied a new potential creation of the sink for carbohydrates and photosynthates allocation. Moreover, stem diameter also increased under the influence of elevated CO_2 (Musa *et al.*, 2016), but they argued it was explained by the heterogeneity of the species used.

Species with notable stomatal responses are presented in **Table 5**. It was found that stomatal conductance has a direct relationship with stomatal density because stomatal size and density are considered the baseline of maximum stomatal conductance (Ramalho *et al.*, 2013; Lahive *et al.*, 2018). The increased stomatal density could be an evolution to withstand the humid understory of tropical rainforests where water deficit is evident (Lahive *et al.*, 2018).

Increased physiological response

The photosynthetic rate also generally improved under elevated CO_2. For example, *Acacia mangium* Willd. can adapt to a higher temperature, a higher concentration of CO_2, and higher light intensity due to their adaptive mechanism of photosystem II and the balance between RuBP carboxylation and regeneration, which are dependent on the photosynthetic processes (Yu & Ong, 2002; Hikosaka *et al.*, 2016; Lee *et al.*, 2019; Ibrahim *et al.*, 2021). This increasing photosynthetic rate may be likely due to the genotypic variations in RuBP carboxylation and the competitive inhibition of oxygenation that improved the Rubisco efficiency (Farquhar & Sharkey, 1982; Liberloo *et al.*, 2007; Darbah *et al.*, 2010). A direct relationship was found between photosynthesis and transpiration, stomatal conductance, and water available for the plant, as mentioned by Lion *et al.* (2019) and De Oliveira & Marenco (2019). The trend can also be explained by knowing that mature leaves of the species have a completely functionally developed organ that can allocate nitrogen resources compared with the younger leaves (Vogado *et al.*, 2021). The changes in the photosynthetic trend in the tropical tree species were due to the additional carbon and the assimilated carbon over the plant's ability to create sinks; hence, the species' response to elevated CO_2 would be to create a new carbon sink (Amthor, 1995; Ceulemans *et al.*, 1999).

Increased transpiration can imply that they could adapt based on water availability and regulate their water potential (Rouhi *et al.*, 2007; Camposeo *et al.*, 2011). This increasing trend can also be directly associated with water vapor pressure and stomatal conductance (Lion *et al.*, 2019). However, an increased transpiration rate under elevated CO_2 can be stressful for the plants knowing that they are losing too much water in their system. Hence, the general response of the plants in this systematic review is inverse because they have an adaptive mechanism for controlling water resources. In the case of water-use efficiency, most species mentioned in the 27 articles, as presented in **Table 5**, highlight that this physiological parameter exhibited an increasing trend under elevated CO_2. The water-use efficiency has an inverse relationship with transpiration and stomatal conductance because those species have a better water conservation mechanism to survive the environmental stress and better carbon assimilation (Amthor, 1995; Ainsworth & Rogers, 2007; Shi *et al.*, 2021). Lahive *et al.* (2018) & Hebbar *et al.* (2020) argued that this increase is attributable to enhanced biomass production rather than lesser water loss by reduced stomatal opening.

Interestingly, the increased water-use efficiency in some trees like *Theobroma cacao* L. did not automatically mean it can tolerate drought stress, specifically when the water is not lost through leaf pathways; hence, not all species with increased water-use efficiency have an adaptive mechanism to drought stress corresponding to the trend among the water-use efficiency, transpiration, and stomatal conductance (Lahive *et al.*, 2018).

Species with positive stomatal conductance response showed adaptive and stable mechanisms to withstand the stress brought by the increasing CO_2 concentration (Lamani *et al.*, 2016). Vu (2005) and Darke *et al.* (1997) mentioned that the changes in stomatal conductance were caused by the indirect effects of CO_2 rather than the direct effect on stomatal aperture, promoting reduced transpiration, improved water use efficiency, and status of tissue water. On the other hand, most species mentioned with intercellular CO_2 concentration as growth parameters showed a positive response. These changes in intercellular CO_2 concentration were associated with the downregulation of photosynthetic rates and sink capacity of photosynthetic products (Flexas *et al.*, 2008; Bader *et al.*, 2010). The trend of intercellular CO_2 concentration is the basis of mesophyll efficiency and net assimilation rates (Sheshshayee *et al.*, 1996; Ogren, 2003). Hence, it was proven that intercellular CO_2 concentration increases as the photosynthetic rate increases (Ramalho *et al.*, 2013; Sekhar *et al.*, 2015). Lastly, an increased Rubisco also increased intercellular CO_2 concentration and carbonic anhydrase activity (Rasineni & Reddy, 2013). The increased trends of RuBisCo and Ru5PK enzymes hint at the potential biochemical capacity reinforcement for the respiration and photosynthetic processes of the species (Ramalho *et al.*, 2013). Hence, the physiological processes in plants affect the trend of biochemical activity.

Negative response of the forest tree species under elevated CO_2

Decreased biomass and morphological growth

Considerably, there were alternative results, given that most trends showed otherwise in the 27 articles. When plants have decreased in height, most of the allocated resources were accumulated in the leaf area of the species (Warrier *et al.*, 2013). Hence, the inverse trend was associated with decreased photosynthetic rates, low carbon fixation, the inability to stimulate greater carbon sinks associated with biomass, and the alteration in the photosynthate distribution in the plant system (Bhatt *et al.*, 2010; Prior *et al.*, 2011). Whereas in some cases, the reduced leaf area and number of leaves under elevated CO_2 was due to the decreasing aboveground biomass simulation and photosynthetic rate as well as the inability to stimulate greater carbon sinks (Rasineni *et al.*, 2013; Musa *et al.*, 2021).

In the reviewed articles, a negative correlation between leaf N/P concentration and leaf biomass production was due to the high accumulation of carbohydrates that led to the dilution of leaf nutrient concentration, reduced resources available for the plant, and reduced allocation of N to Rubisco during photosynthesis (Sakai *et al.*, 2006; Shi *et al.*, 2021). The delayed greening of plants under elevated CO_2 was related to the decreased trend of leaf N content resulting in low nutritional value in the plant system and underdeveloped photosynthetic apparatus (Vogado *et al.*, 2021; Kursar & Coley, 2003). Some species with reduced leaf N content are also presented in **Table 5**. In the case of branch numbers, the reduction in branches stimulated the apical dominance promoting jorquetting in trees (Hebbar *et al.*, 2020). Hence, in general, the reduction of morphological characteristics of the plants was attributed to reduced biomass production and physiological processes such as photosynthesis, transpiration, and respiration, among others.

Decreased physiological response

Concerning the physiological parameters, the reduced photosynthetic rate per total leaf area was elaborated by the fact that the plant growth was not maintained in the long run because exposure to elevated CO_2 can require losses in carbon assimilation (Korner & Miglietta, 1994; Arenque, 2014). In another case, the low pot space accounted for low nutrient uptake resulting in the reduced movement of photosynthetic products to the root system of their study species (Shi *et al.*, 2021).

Table 5. Summary table of the species' response to elevated CO_2 as mentioned in the 27 articles.

Tree species	Positive response	Negative response	No response	Reference
Tectona grandis Linn. F., (Lamiaceae)	RB; RL; TPB; PR; ICC	H		Warrier *et al.* (2013); Raj *et al.* (2014)
Ailanthus excelsa Roxb. (Simaroubaceae)	SB; RL; TR	CC		
Casuarina equisetifolia L. (Casuarinaceae)	SB		RL	Warrier *et al.* (2013)
Gmelina arborea Roxb. (Lamiaceae)	TPB; NB; H; SDi; RW; ICC; RA	TR		Rasineni & Reddy 2013; Rasineni *et al.* 2013)
Schima superba Gardn. & Champ. (Theaceae); *Syzygium hancei* Merr. & Perry (Myrtaceae); *Ormosia pinnata* (Lour.) Merr. (Fabaceae); *Castanopsis hystrix* J. D. Hooker & Thomson ex A. de Candolle (Fagaceae); *Acmena acuminatissima* (Bl.) Merr. et Perry (Myrtaceae)	TPB			Yan *et al.* (2014)
Senna reticulata (Willd.) H. S. Irwin & Barneby (Fabaceae)	TPB	PR; LN	LA; SC	Arenque *et al.* (2014)
Morus alba L. (Moraceae)	TPB; LN; H; PR; ICC	TR		Sekhar *et al.* (2015); Shi *et al.* (2021)
Azadirachta indica A. Juss. (Meliaceae)	TPB; LN; RL; RW; PR; SC; ICC			Raj *et al.* (2014); Janani *et al.* (2016)
Melia dubia Cav. (Meliaceae)	TPB; LN; PR; SC	RW; ICC		Janani *et al.* (2016)
Theobroma cacao L. (Malvaceae)	TPB; LN; SD; PR; WUE	NB	LA; SL; SC; TR; CC	Lahive *et al.* (2018); Lahive *et al.* (2020); Hebbar *et al.* (2020)
Shorea platycarpa F.Heim. (Dipterocarpaceae)	H; SDi	SB; LA	TPB	Musa *et al.* (2016); Musa *et al.* (2021)
Macaranga pruinosa (Miq.) Mull.Arg. (Euphorbiaceae)	TPB; H; SDi			Musa *et al.* (2021)
Trichospermum galeottii (Turcz.) Kosterm (Malvaceae); *Cecropia insignis* Liebm. (Urticaceae); Ochroma pyramidale (Cav.) Urban. (Malvaceae); *Trema micrantha* L. (Cannabaceae); *Ficus insipida* Willd. (Moraceae); *Guazuma ulmifolia* Lam. (Malvaceae); *Cecropia peltata* L. (Moraceae); *Cecropia longipes* Pitt. (Urticaceae)	TPB; PR	TR		Thompson *et al.* (2019)
Sandalum album L. (Santalaceae)	LA; H; PR; TR; SC			Lamani *et al.* (2016)
Coffea arabica cv. *catuai* L. (Rubiaceae)	H; PR; WUE		SC; LNC	Ghini *et al.* (2015)
Coffea arabica cv. *obata* L. (Rubiaceae)	H; PR; WUE	LNC	SC	
Coffea arabica L. (Rubiaceae); C*offea canephora* P. ex Fr. (Rubiaceae)	SS; PR; WUE; RuBisCo and Ru5PK enzymes	SD	LA; SC; CC	Ramalho *et al.* (2013)
Morus multicaulis Perr. var. QiangSang (Moraceae)	TPB; LN; H; SDi	CC; PR; SC; TR; Leaf P content; LNC		Shi *et al.* (2021)
Morus multicaulis Perr. var. NongSang (Moraceae)	TPB; LN; H	CC; PR; SC; TR	SDi	
Butea monosperma (Lam.) Taub. (Fabaceae)			H; TPB	Singh *et al.* (2019)

Table 5. (Con't)

Tree species	Positive response	Negative response	No response	Reference
Carapa surinamensis Miq. (Meliaceae)	TPB; PR; WUE	SC	LA; ICC	De Oliveira & Marenco (2019)
Acacia mangium Willd. (Fabaceae)	PR; WUE		TR; SC	Ibrahim *et al.* (2021)
Buchanania arborescens (Blume) Blume (Anacardiaceae)	WUE	TR	PR; SC	
Dillenia suffruticosa (Griffth) Martelli	WUE	TR; SC	PR	
Calophyllum inophyllum L.	WUE	TR	PR; SC	
Ploiarium alternifolium (Vahl) Melch.	PR; SC; WUE		TR	
Shorea parvifolia Dyer (Dipterocarpaceae)	PR; TR; SC	WUE		Lion *et al.* (2019)
Dalbergia retusa Hemsl. (Fabaceae); *Inga punctata* Willd. (Fabaceae); *Ormosia macrocalyx* Ducke (Fabaceae); *Schizolobium parahyba* (Vell.) S. F. Blake (Fabaceae); *Chrysophyllum cainito* L. (Sapotaceae); *Coccolaba uvifera* (L.) L. (Polygonaceae); *Hieronyma alchorneoides* Allemão (Euphorbiaceae); *Pachira quinate* W.S. Alverson (Malvaceae); *Swietenia macrophylla* King. (Meliaceae)	TPB; PR; WUE	SC		Cernusak *et al.* (2011); Trierweiler *et al.* (2018)
Brachychiton acerifolius (A.Cunn. ex G.Don) Macarthur & C.Moore (Malvaceae)	LA; PR; SC; WUE; CC			Vogado *et al.* (2022)
Phaleria clarodendron (F.Muell.) Benth. (Thymelaeaceae)	LA; PR; SC; WUE; CC			
Terminalia catappa L. (Combataceae)	PR; SC; WUE; CC	LNC	LA	
Psidium guajava L. cv. Pedro Sato (Myrtaceae)			TPB; H; LN; RL; Total phenolic compounds	De Rezende *et al.* (2014)
Tabebuia rosea (Bertol.) DC. (Bignoniaceae)	PR	SC	LNC; SD	Slot *et al.* 2020

Note: CC: Chlorophyll content; H: Height; ICC: Intercellular CO_2 concentration; LA: Leaf area; LN: Leaf number; LNC: Leaf Nitrogen content; NB: Number of branches; PR: Photosynthetic rate; RA: Rubisco activity; RB: Root biomass; RL: Root length; RW: Root weight; SB: Shoot biomass; SC: Stomatal conductance; SD: Stomatal density; SDi: Stem diameter; SL: Stomatal length; SS: Stomatal Size; TPB: Total plant biomass; TR: Transpiration rate; WUE: Water-use efficiency

A reduction in transpiration rate under elevated CO_2 means plants can withstand climate change scenarios, specifically high CO_2 concentration and drought, because of their water conservation mechanism (Dang *et al*., 2008; Onoda *et al*., 2009; Rasineni *et al*., 2013; Sekhar *et al*., 2015). Moreover, Thompson *et al.* (2019) revealed that the average transpiration rate of the eight tropical tree seedlings presented in **Table 5** was reduced significantly under 800 ppm, and this would furtherly reduce the foliar Phosphorus concentration in some tropical trees. Thompson *et al.* (2019) also reported the reduced stomatal conductance as well as the leguminous and non-leguminous tropical tree species used by Cernusak *et al.* (2011) under elevated CO_2. It explained the increasing leaf temperature during photosynthesis, increasing leaf-to-air vapor pressure difference. Moreover, the transpiration rate and stomatal conductance have a direct relationship, but the water use efficiency is inversely related. Generally, if a species exhibited increasing water use efficiency and decreasing transpiration rate and stomatal conductance, they have a higher chance of adapting and surviving drought and elevated CO_2 stresses, as mentioned in the reviewed papers (Warrier *et al*., 2013; Raj *et al.*, 2014; Sekhar *et al.*, 2015; Janani *et al.*, 2016; Shi *et al.*, 2021). Hence, the lower transpiration and stomatal conductance can be a parameter to distinguish which species can withstand future climate change.

Furthermore, decreasing intercellular CO_2 concentration altered the mesophyll efficiency and net assimilation rates (Sheshshayee *et al.*, 1996; Ogren, 2003; Janani *et al.*, 2016). Lastly, reduced chlorophyll content affected the stability of the non-structural carbohydrates that inhibit the production of chloroplasts and reduced Nitrogen investment in photosynthesis when exposed to elevated CO_2 (Delucia *et al.*, 1985; Epron *et al.*, 1996; Warrier *et al.*, 2013; Vogado *et al.*, 2021). Other notable species mentioned in the 27 articles with reduced photosynthetic rate, transpiration rate, stomatal density, and water-use efficiency are also presented in **Table 5**.

No significant response of the forest tree species under elevated CO_2

Some species did not respond significantly to the elevated CO_2. In the case of biomass production, De Rezende *et al.* (2014) countered the previous results and revealed that the changes in dry biomass had no significant differences from the increasing CO_2 concentration. However, exposure to different levels of CO_2 can lead to the accumulation of starch and tannins, as mentioned in their paper.

Morphologically, the leaf area of species in reviewed articles (**Table 5**) showed insignificant differences among the CO_2 treatments. In root length, Warrier *et al.* (2013) and De Rezende *et al.* (2014) reported no significant differences between control and experimental treatments. Furthermore, the stomatal length, index, and density had no significant differences between ambient and elevated CO_2 (Cernusak *et al.*, 2011; Lahive *et al.*, 2018).

Physiologically, there were parameters mentioned that also did not exhibit any significant differences. Three papers agreed that the transpiration rate of plant species had no significant changes in elevated CO_2 (Lahive *et al.*, 2018; Lahive *et al.*, 2020; Hebbar *et al.*, 2020). There were also reported cases that the stomatal conductance had no significant differences with elevated CO_2 concentration (Ramalho *et al.*, 2013; Arenque *et al.*, 2014; Ghini *et al.*, 2015; De Oliveira & Marenco, 2019; Slot *et al.*, 2021), same case with the biochemical activity such as chlorophyll content, chlorophyll a+b, and total carotenoids (Lahive *et al.*, 2018). Moreover, the phenolic compounds and flavonoids found in the roots, stems, and leaves had no significant differences between ambient and elevated CO_2, but there were higher levels of these substances in the root system of the species (De Rezende *et al.*, 2014). Other species with no significant response on their grown parameters are also shown in **Table 5**.

Research gaps

One of the prominent research gaps in this study is the limited studies in the Philippines about the effect of elevated CO_2 in plants. While most research papers in research databases were conducted and published within the tropical region, they have yet to be done in the Philippines. If there are studies about elevated CO_2, they were using crops such as rice and corn, that did not qualify for the screening method because they should be tropical trees. Hence, a developing country with megadiverse biodiversity and a biodiversity hotspot must conduct various research about the effects of CO_2 enrichment on the growth of tropical forest trees.

On the other hand, the study duration of the effects of the elevated CO_2 in trees was identified as another research gap. The structure, morphology, and physiological responses of the younger plant are different from the mature plants that already underwent secondary growth, development of an adaptive mechanism to various environmental stresses, and establishment of their firm shape and form (Baucher *et al.*, 2007; Spicer & Groover, 2010; Ragni & Greb, 2018). The result inconsistencies were found in the reviewed articles (Ramalho *et al.*, 2013; Warrier *et al.*, 2013; Raj *et al.*, 2014; Ghini *et al.*, 2015; Janani *et al.*, 2016) concerning the plant height, transpiration rate, and stomatal conductance. There was still a vague understanding of the short-term and long-term effects of the elevated CO_2 and the steps needed to eradicate this, knowing that the plants underwent the principle of hormesis that generally alters their metabolic processes. Fortunately, Cernusak *et al.* (2013) provided some opportunities and recommendations to diminish the variability and uncertainty in the study of CO_2 enrichment.

Lastly, the methodology of CO_2 enrichment in plant study was one of the critical research gaps in reviewed articles. Twenty-four articles had a controlled approach to elevated CO_2, while three articles used an observational approach using solely the FACE method. The systematic reviews about the impacts of the FACE method on plants have a well-studied reputation (Ainsworth & Long *et al.*, 2004 & 2020; Allen *et al.*, 2020). Drake *et al.* (1985) pointed out that the FACE method has the closest simulation to the environmental settings compared with the other methods. However, organizing and implementing the FACE method requires high maintenance and cost. The question is how instantaneous the potential development of a low-cost, high-efficient, and sustainable CO_2 enrichment method with a lesser error of comparison in a natural environmental setting is possible. Providing solutions to this gap can change our understanding of the impacts of elevated CO_2 on plants' physiology, morphology, and biomass production.

CONCLUSIONS AND RECOMMENDATIONS

Tropical forest trees are excellent at capturing and storing vast amounts of atmospheric carbon. However, elevated CO_2 concentration affects biomass production as well as the morphological and physiological processes of tropical trees, as verified in this systematic review. Variability in biomass production and physiological and morphological responses of tropical trees have shown that some species can withstand worsening climate change, but others cannot. Generally, species with adaptive mechanisms to climate change follow a trend of reduced transpiration and stomatal conductance while exhibiting positive water use efficiency. It was also found that the specific changes in biomass production and morphological responses complemented the physiological response of the tropical tree species under the elevated CO_2 treatment. If biomass production decreases, morphological and physiological responses also decrease. Hence, these parameters are useful in determining the responses of plants to any environmental stresses.

This systematic review further highlighted the gaps in CO_2 enrichment research, which can be opportunities for future research. To understand current research trends, a consistent, systematic review of the effects of elevated CO_2 concentration must be conducted once every decade. The scope of the future systematic review should be in a more extended period (> 11 yr) and include different biomes to generate a more comprehensive knowledge about the field. In addition, a wide range of literature, such as conference papers, book chapters, or gray literature, can also be explored to create a more extensive systematic review concerning climate research. Lastly, more climate-related research can lessen the impact of climate change through successful policy formulation, sustainable economic development, and food security enhancement.

ACKNOWLEDGMENTS

The author would like to extend his sincerest gratitude to Dr. Marilyn S. Combalicer, his academic adviser, for guidance and for providing the opportunity to publish. The author would also like to thank the Department of Forest Biological Science and colleagues for their support.

LITERATURE CITED

Ainsworth, E. A. & Rogers, A. (2007). The response of photosynthesis and stomatal conductance to rising [CO_2]: Mechanisms and environmental interactions. *Plant Cell Environment, 30*, 258–270.

Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist*, *165*(2), 351–372.

Ainsworth, E. A., & Long, S. P. (2021). 30 years of free-air carbon dioxide enrichment (FACE): What have we learned about future crop productivity and its potential for adaptation? *Global change biology*, *27*(1), 27–49.

Aliyu, M. B. (2017). Efficiency of Boolean search strings for information retrieval. *American Journal of Engineering Research*, 6(11), 216–222.

Allen, L., Kimball, B., Bunce, J., Yoshimoto, M., Harazono, Y., Baker, J., Boote, K., & White, J. (2020). Fluctuations of CO_2 in Free-Air CO_2 Enrichment (FACE) depress plant photosynthesis, growth, and yield. *Agricultural and Forest Meteorology, 284*, 107899. doi:10.1016/j.agrformet.2020.107899

Amthor, J. S. (1995). Predicting effects of atmospheric CO_2 partial pressure on forest photosynthesis. *Global Ecology and Biogeography Letters*, 22, 243–274.

Arenque, B. C., Grandis, A., Pocius, O., de Souza, A. P., & Buckeridge, M. S. (2014). Responses of *Senna reticulata*, a legume tree from the amazonian floodplains, to elevated atmospheric CO_2 concentration and waterlogging. *Trees - Structure and Function*, 28(4), 1021–1034.

Avila, R. T., de Almeida, W. L., Costa, L. C., Machado, K. L. G., Barbosa, M. L., de Souza, R. P. B., Martino, P. B., Juárez, M. A. T., Marçal, D. M. S., Martins, S. C. V., Ramalho, J. D. C., & DaMatta, F. M. (2020). Elevated air [CO_2] improves photosynthetic performance and alters biomass accumulation and partitioning in drought-stressed coffee plants. *Environmental and Experimental Botany*, 177, 104137. doi:10.1016/j.envexpbot.2020.10413.

Bader, K-F. M., Siegwolf, R., & Korner, C. (2010). Sustained enhancement of photosynthesis in mature deciduous forest trees after 8 years of free air CO_2 enrichment. *Planta*, 232, 1115–1125.

Bassham, J. A. (2003). Mapping the carbon reduction cycle: a personal retrospective. *Photosynthesis Research*, 76, 35–52.

Baucher, M., Jaziri, M. E., & Vandeputte, O. (2007). From primary to secondary growth: origin and development of the vascular system. *Journal of Experimental Botany*, 58(13), 3485–3501.

Betts, R. (2021). Met Office: Atmospheric CO_2 now hitting 50% higher than preindustrial levels. Retrieved from: <https://www.carbonbrief.org/met-office-atmospheric-co2-now-hitting-50-higherthan-pre-industrial-levels>.

Bhatt, R. K., Baig, M. J., Tiwari, H. S., & Roy, S. (2010). Growth, yield and photosynthesis of *Panicum maximum* and *Stylosanthes hamata* under elevated CO_2. *Journal of Environmental Biology*, 31, 549–552.

Booth, A., Noyes, J., Flemming, K., Moore, G., Tuncalp, O., & Shakibazadeh, E. (2019). Formulating questions to explore complex interventions within qualitative evidence synthesis. *BMJ Global Health*, 4(Suppl 1): e001107. doi:10.1136/bmjgh-2018-001107.

Camposeo, S., Palasciano, M., Vivaldi, G. A., & Godini, A. (2011). Effect of increasing climatic water deficit on some leaf and stomatal parameters of wild and cultivated almonds under Mediterranean conditions. *Scientia Horticulturae*, 127(3), 234–241.

Cernusak, L. A., Winter, K., Dalling, J. W., Holtum, J. A., & Wright, S. J. (2013). Tropical forest responses to increasing atmospheric CO_2: current knowledge and opportunities for future research. *Functional Plant Biology*, 40, 531–551.

Cernusak, L. A., Winter, K., Martínez, C., Correa, E., Aranda, J., Garcia, M., Jaramillo, C. & Turner, B. L. (2011). Responses of legume versus nonlegume tropical tree seedlings to elevated CO_2 concentration. *Plant Physiology*, 157(1), 372–385.

Ceulemans, R., Janssens, I. A., & Jach, M. E. (1999). Effects of CO_2 enrichment on trees and forests: Lessons to be learned in view of future ecosystem studies. *Annals of Botany*, 84, 577–590.

Corlett, R. T. (2018). Tropical Rainforests and Climate Change. Yunnan, China: Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences.

Curtis, P. S. & Wang, X. (1998). A meta-analysis of elevated CO_2 effects on woody plant mass, form, and physiology. *Oecologia*, 113, 299–313.

Dang, Q. L., Maepea, J. M., & Parker, W. H. (2008). Genetic variation of ecophysiological responses to CO_2 in *Picea gluca* seedlings. *Open Forest Science Journal*, 1, 68–79.

Darbah, J. N. T., Kubiske, M. E., Nelson, N., Kets, K., Riikonen, J., Sober, A., Rouse, L., & Karnosky, D. F. (2010). Will photosynthetic capacity of aspen trees acclimate after long-term exposure to elevated CO_2 and O3? *Environmental Pollution*, 158, 983–991.

Darke, B. G., Gonzales-Meler, M., & Long, S. P. (1997). More efficient plants: A consequence of rising atmospheric CO_2? Annual Review of *Plant Physiology and Plant Molecular Biology*, 48, 609–639.

De Oliveira, M. F. & Marenco, R. A. (2019). Gas exchange, biomass allocation and water-use efficiency in response to elevated CO_2 and drought in andiroba (*Carapa surinamensis*, Meliaceae). *iForest*, 12, 61–68.

De Rezende, F. M., Pereira de Souza, A., Silveira Buckeridge, M., & Maria Furlan, C. (2014). Is guava phenolic metabolism influenced by elevated atmospheric CO_2? *Environmental Pollution*, 196, 483–488.

Delucia, E. H., Sasek, T. W., & Strain, B. R. (1985). Photosynthetic inhibition after long-term exposure to elevated levels of atmospheric carbon dioxide. *Photosynthesis Research*, 7, 175–84.

Dickson, R. E., Coleman, M. D., Riemenschneider, D. E., Isebrands, J. G., Hogan, G. D., & Karnosky, D. F. (1998). Growth of five hybrid poplar genotypes exposed to interacting elevated CO_2 and O3. *Canadian Journal of Forest Research*, 28, 1706–1716.

Epron D., Liozon R., & Mousseau M. (1996). Effects of elevated CO_2 concentration on leaf characteristics and photosynthetic capacity of beech (*Fagus sylvatica*) during the growing season. *Tree Physiology*, 16, 425–32.

Farquhar, G. D. & Sharkey, T. D. (1982). Stomatal conductance and photosynthesis. *Annual Review of. Plant Physiology*, 33, 317–345.

Flexas, J., Ribas-Carbo, M., Diaz-Espejo, A., Galmés, J., & Medrano, H. (2008). Mesophyll conductance to CO_2: current knowledge and future prospects. *Plant, Cell & Environment*, 31, 601–621.

Ghasemzadeh, A, Jaafar, H. Z. E., & Rahmat, A. (2010). Antioxidant activities, total phenolics and flavonoids content in two varieties of Malaysia young ginger (*Zingiber officinale* Roscoe). *Molecules*, 15(6), 4324–4333.

Ghasemzadeh, A. & Jaafar, H. Z. E. (2011). Effect of CO_2 enrichment on some primary and secondary metabolites synthesis in Ginger (*Zingiber officinale* Roscoe). *International Journal of Molecular Science*, 12(2), 1101–1114.

Ghini, R., Torre-Neto, A., Dentzien, A. F. M., Guerreiro-Filho, O., Iost, R., Patrício, F. R. A., Prado, J. S. M., Thomaziello, R. A., Bettiol, W., & DaMatta, F. M. (2015). Coffee growth, pest and yield responses to free-air CO_2 enrichment. *Climatic Change*, 132(2), 307–320.

Hebbar, K. B., Apshara, E., Chandran, K. P., & Prasad, P. V. V. (2020). Effect of elevated CO_2, high temperature, and water deficit on growth, photosynthesis, and whole plant water use efficiency of cocoa (*Theobroma cacao* L.). *International Journal of Biometeorology*, 64(1): 47–57.

Hernandez, J. O., Maldia, L. S. J., & Park, B. B. (2020) Research trends and methodological approaches of the impacts of windstorms on forests in tropical, subtropical, and temperate zones: Where are we now and how should research move forward? *Plants*, 9, 1709; doi:10.3390/plants9121709.

Hikosaka, K., Noguchi, K.., & Terashima, I. (2016). Modeling leaf gas exchange. In: Hikosaka, K., Niinemets, Ü., & Anten, N. P. R. (eds.). *Canopy Photosynthesis: From Basics to Applications.* pp. 61–100. Springer.

Ibrahim, M. H., Sukri, R. S., Tennakoon, K. U., Le, Q. V., & Metali, F. (2021). Photosynthetic responses of invasive Acacia mangium and co-existing native heath forest species to elevated temperature and CO_2 concentrations. *Journal of Sustainable Forestry*, 40(6), 573–593.

IPCC [Intergovernmental Panel on Climate Change]. (2013). Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Janani, S., Priyadharshini, P., Jayaraj, R., Buvaneswaran, C., & Warrier, R. (2016). Growth, physiological and biochemical responses of Meliaceae species - *Azadirachta indica* and *Melia dubia* to elevated CO_2 concentrations. *Journal of Applied Biology and Biotechnology*, *4*, 052–060.

Kallarackal, J. & Roby, T. J. (2012). Responses of trees to elevated carbon dioxide. *Biodiversity Conservation*, 21, 1327–1342.

Khurana, E. & Singh, J. S. (2001). Ecology of seed and seedling growth for conservation and restoration of tropical dry forest: A review. *Environmental Conservation*. doi:10.1017/S0376892901000042.

Korner, C. & Miglietta, F. (1994). Long-term effects of naturally elevated CO_2 on Mediterranean grassland and forest trees. *Oecologia*, *99*, 343–351.

Kumar, S., Chaitanya, B. S. K., Ghatty, S., & Reddy, A. R. (2014). Growth, reproductive phenology and yield responses of a potential biofuel plant, *Jatropha curcas* grown under projected 2050 levels of elevated CO_2. *Physiologia Plantarum*, *152*, 501–519.

Kursar, T. A. & Coley, P. D. (2003). Convergence in defense syndromes of young leaves in tropical rainforests. *Biochemical Systematics & Ecology*, *31*, 929–49.

Lacis, A. A., Hansen, J. E., Russell, G. L., Oinas, V., & Jonas, J. (2013). The role of long-lived greenhouse gases as principal LW control knob that governs the global surface temperature for past and future climate change. Tellus B, *65*, 19734. doi:10.3402/tellusb.v65i0.19734.

Lahive, F., Hadley, P., & Daymond, A. J. (2018). The impact of elevated CO_2 and water deficit stress on growth and photosynthesis of juvenile cacao (*Theobroma cacao* L.). *Photosynthetica*, *56*, 911–920.

Lamani, N., Shivaprasad, D., & Swamy, K. R. (2016). Effect of elevated carbon dioxide concentration on photosynthetic and transpiration rate in Sandal (*Santalum album* L.). *Proceedings of the International Academy of Ecology and Environmental Sciences*, *6*(2), 44–52.

Leakey, A. D. B., Press, M. C., Scholes, J. D., & Watling, J. R. (2002). Relative enhancement of photosynthesis and growth at elevated CO_2 is greater under sunflecks than uniform irradiance in a tropical rain forest tree seedling. *Plant, Cell & Environmen*t, *25*(12), 1701–1714.

Lee, Q. V., Tennakoon, K. U., Metali, F., & Sukri, R. S. (2019). Photosynthesis in co-occurring invasive *Acacia* spp. and native Bornean heath forest trees at the post-establishment invasion stage. *Journal of Sustainable Forestry*, *38*(3), 230–243.

Liberloo, M., Tulva, I., Raim, O., Kull, O., & Ceulemans, R. (2007). Photosynthetic stimulation under long-term CO_2 enrichment and fertilization is sustained across a closed populous canopy profile (EUROFACE). *New Phytologist*, *173*, 537–549.

Lindsey, R. (2007). Tropical Deforestation. Earth Observatory – NASA. Retrieved on 15 May 2021 from: <https://earthobservatory.nasa.gov/features/Deforestation>.

Lion, M., Remperi, S., Chuah, N. J. & Shamsuddin, S.A. (2019). The study on transpiration and water use efficiency of *Shorea parvifolia* under elevated carbon dioxide concentration in the tropical forest. *International Journal of Agriculture, Forestry and Plantation*, *8*, 98–105.

Livoreil, B., Glanville, J., Haddaway, N. R., Bayliss, H., Bethel, A., de Lachapelle, F. F., Robalino, S., Savilaakso, S., Zhou, W., Petrokofsky, G., & Frampton, G. (2017). Systematic searching for environmental evidence using multiple tools and sources. *Environmental Evidence*, *6*(1), 23. doi:10.1186/s13750-017-0099-6.

Lloyd, J. & Farquhar, G. D. (2008). Effects of rising temperatures and CO_2 on the physiology of tropical forest trees. *Philosophical Transactions of Royal Society B*, *363*, 1811–1817.

Lovelock, C. E., Virgo, A., Popp, M., & Winter, K. (1999). Effects of elevated CO_2 concentrations on photosynthesis, growth and reproduction of branches of the tropical canopy tree species, *Luehea seemannii* Tr. and Planch. *Plant, Cell & Environment*, *22*(1), 49–59.

Miller, S. A. & Forrest, J. L. (2001). Enhancing your practice through evidence-based decision making: PICO, learning how to ask good questions. *Journal of Evidence Based Dental Practice*, *1*, 136–141.

Minnesota Population Center (2020). Integrated Public Use Microdata Series, International: Version 7.3 [World Map dataset]. Minneapolis, MN: IPUMS. doi:10.18128/D020.V7.3

Mndela, M., Tjelele, J. T., Madakadze, I. C., Mangwane, M., Samuels, I. M., Muller, F., & Pule, H. T. (2022). A global meta-analysis of woody plant responses to elevated CO_2: implications on biomass, growth, leaf N content, photosynthesis and water relations. *Ecological Processes*, *11*, 52. doi:10.1186/s13717-022-00397-7

Musa, N. L. W., Nizam, M. S., Radziah, C. M. Z. C., & Juliana, W. A. W. (2021). Growth responses of light demanding and shade tolerant peat swamp forest saplings to elevated CO_2. *Journal of Environmental Biology*, *42*(3), 735–743.

Musa, N. L. W., Wan Juliana, W. A., Nizam, M. S., & Che Radziah, C. M. Z. (2017). Effects of elevated atmospheric CO_2 on photosynthesis, growth and biomass in *Shorea platycarpa* F. Heim (Meranti Paya). *Sains Malaysiana*, *46*(9), 1421–1428.

Needham, J. F., Chambers, J., Fisher, R., Knox, R., & Koven, C. D. (2020). Forest responses to simulated elevated CO_2 under alternate hypotheses of size- and age-dependent mortality. *Global Change Biology*, *26*(10), 5734–5753.

Ogren, W. L. (2003). Affixing the O to RuBisCo: Discovering the source of photorespiratory glycolate and its regulation. *Photosynthesis Research*, *76*, 53–63.

Onoda, Y., Hirose, T., & Hikosaka, K. (2009). Does leaf photosynthesis adapt to CO_2- enriched environments? An experiment on plants originating from three natural CO_2 springs. *New Phytologist*, *182*, 698–709.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S. , & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *British Medical Journal*, *372*. doi:10.1136/bmj.n7.

Prior, S. A., Runion, G. B., Marble, S. C., Rogers, H. H., Gilliam, C. H., & Torbert, H. A. (2011). A review of elevated atmospheric CO_2 effects on plant growth and water relations: Implications for horticulture. *Horticulture & Horticultural Science*, *46*(2), 158–162.

QGIS Development Team. (2020). QGIS Geographic Information System. Open-Source Geospatial Foundation Project. Retrieved from: <http://qgis.osgeo.org>.

Ragni, L. & Greb, T. (2018). Secondary growth as a determinant of plant shape and form. *Seminars in Cell & Developmental Biology*, *79*, 58–67.

Rai, A., Singh, A.K., Singh, N., & Ghoshal, N. (2020). Effect of elevated CO_2 on litter functional traits, mass loss and nutrient release of two subtropical species in free air carbon enrichment facility. *Environmental and Experimental Botany, 172*, doi:10.1016/j.envexpbot.2020.103994.

Raj, E. E., Buvaneswaran, C., Menason, E., & Vijayalakshmi, C. (2014). Physiological response of tropical tree species to elevated CO_2 levels at seedling stage. *Indian Journal of Ecology*, *41*(1), 16–22.

Ramalho, J. C., Rodrigues, A. P., Semedo, J. N., Pais, I. P., Martins, L. D., Simões- Costa, M. C., Leitão, A. E., Fortunato, A. S., Batista-Santos, P., Palos, I. M., Tomaz, M. A., Scotti-Campos, P., Lidon, F. C., & DaMatta, F. M. (2013). Sustained photosynthetic performance of *Coffea* spp. under long-term enhanced CO_2. *PLOS ONE*, *8*(12). doi:10.1371/journal.pone.0082712

Rasineni, G. K. & Reddy, A. R. (2013). Influence of Elevated CO_2 Concentration on Photosynthesis and Biomass Yields in a Tree Species, Gmelina arborea Roxb. Springer, Berlin, Heidelberg. doi:10.1007/978-3-642-32034-7_167

Rasineni, G. K., Guha, A., & Reddy, A. R. (2013). Elevated CO_2 atmosphere significantly increased photosynthesis and productivity in a fast growing tree species, *Gmelina arborea* Roxb. *Climate Change and Environmental Sustainability*, *1*(1), 81–94.

Reichgelt, T., D'Andrea, W. J., Valdivia-McCarthy, A. C., Fox, B. R. S., Bannister, J. M., Conran, J. G., Lee, W. G., & Lee, D. E. (2020). Elevated CO_2, increased leaf-level productivity, and water-use efficiency during the early Miocene. *Climate of the Past*, *16*(4), 1509–1521.

Rouhi, V., Samson, R., Lemeur, R., & Damme, V. (2007). Photosynthetic gas exchange characteristics in three different almond species during drought stress and subsequent recovery. *Environmental and Experimental Botany*, *59*, 117–129.

Sakai, H., Hasegawa, T., & Kobayashi, K. (2006). Enhancement of rice canopy carbon gain by elevated CO_2 is sensitive to growth stage and leaf nitrogen concentration. *New Phytologist*, *170*, 321–332.

Sekhar, K. M., Sreeharsha, R. V., & Reddy, A. R. (2015). Differential responses in photosynthesis, growth and biomass yields in two mulberry genotypes grown under elevated CO_2 atmosphere. *Journal of Photochemistry and Photobiology*, *151*, 172–179.

Sheshshayee, M. S., Krishna Prasad, B. T., Natraj, K. N., Shankar, A. G., Prasad, T. G., & Uday Kumar, M. (1996). Ratio of intercellular CO_2 concentration to stomatal conductance is a reflection of mesophyll efficiency. *Current Science*, *70*(7), 672– 675.

Shi, S., Xu, X., Dong, X., Xu, C., Qiu, Y., & He, X. (2021). Photosynthetic acclimation and growth responses to elevated CO_2 associate with leaf nitrogen and phosphorus concentrations in mulberry (*Morus multicaulis* Perr.). *Forests*, *12*(6), 660. MDPI AG. doi:10.3390/f12060660.

Singh, A. K., Rai, A., Kushwaha, M., Chauhan, P. S., Pandey, V., & Singh, N. (2019). Tree growth rate regulate the influence of elevated CO_2 on soil biochemical responses under tropical condition. *Journal of Environmental Management*, *231*, 1211–1221.

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., Boyd, K. A., Craig, N., French, D. P., McIntosh, E., Petticrew, M., Rycroft-Malone, J., White, M., & Moore, L. (2021). Framework for the development and evaluation of complex interventions: gap analysis, workshop and consultation-informed update. *Health Technology Assessment* (Winchester, England), *25*(57), 1–132.

Slot, M., Rifai, S. W., & Winter, K. (2021). Photosynthetic plasticity of a tropical tree species, *Tabebuia rosea*, in response to elevated temperature and [CO_2]. *Plant, Cell & Environment*, *44*, 2347– 2364.

Sohrabi, C., Franchi, T., Mathew, G., Kerwan, A., Nicola, M., Griffin, M., Agha, M., & Agha, R. (2021). PRISMA 2020 statement: What's new and the importance of reporting guidelines. *International Journal of Surgery*, 88, 105918. doi:10.1016/j.ijsu.2021.105918.

Spicer, R. & Groover, A. (2010). Evolution of development of vascular cambia and secondary growth. *New Phytologist*, *186*, 577–592.

Drake, B. G., Rogers, H. H., & Allen, L H., Jr. (1985). Methods of exposing plants to elevated Carbon dioxide. In B. R. Strain & J. D. Cure (Eds.), Direct effects of increasing carbon dioxide on vegetation (pp. 13-31). United States. doi:10.2172/6134866

Tang, K. H. D. (2019). Impacts of climate change on tropical rainforest's adaptive capacity and ecological plasticity. *Climate Change Facts, Impacts and Solutions, 1*, 1–5.

Thompson, J. B., Slot, M., Dalling, J. W., Winter, K., Turner, B. L., & Zalamea, P. C. (2019). Species-specific effects of phosphorus addition on tropical tree seedling response to elevated CO_2. *Functional Ecology, 33*, 1871–1881.

Tietze, H. S. E., Joshi, J., Pugnaire, F. I., & Dechoum, M. dS. (2019). Seed germination and seedling establishment of an invasive tropical tree species under different climate change scenarios. *Australia Ecology*, *44*(16). doi:10.1111/aec.12809.

Vogado, N. O., Cheesman, A. W., & Cernusak, L. A. (2021). Delayed greening during leaf expansion under ambient and elevated CO_2 in tropical tree seedlings. *Australian Ecology, 47*, 530–540.

Vu, J. C. V. (2005). Acclimation of peanut (Arachis hypogaea L.) leaf photosynthesis to elevated growth CO_2 and temperature. *Environmental and Experimental Botany, 53*, 85–95.

Wang, D., Heckathorn, S. A., Wang, X., & Philpott, S. M. (2012). A meta-analysis of plant physiological and growth responses to temperature and elevated CO_2. *Oecologia, 169*, 1–13.

Warrier, R. R., Buvaneswaran, C., Priyadharshini, P., & Jayaraj, R. S. C. (2013). Growth response of three plantation species of the tropics exposed to elevated CO_2 levels. *Journal of Forestry Research, 24*(3), 449–456.

Yan, J., Zhang, D., Liu, J., & Zhou, G. (2014). Interactions between CO_2 enhancement and N addition on net primary productivity and water-use efficiency in a mesocosm with multiple subtropical tree species. *Global Change Biology, 20*(7), 2230–2239.

Yu, H. & Ong, B. L. (2002). The effect of phyllode temperature on gas exchange and chlorophyll fluorescence of *Acacia mangium*. *Photosynthetica*, *40*(4), 635–639.

Zak, D. R., Pregitzer, K. S., Curtis, P. S., Vogel, C. S., Holmes, W. E., & Lussenhop, J. (2000). Atmospheric CO_2, soil-N availability, and allocation of biomass and nitrogen by *Populus tremuloides*. *Ecological Applications*, 10(1), 34–46.

Zhu, C., Zemg, Q., Yu, H., Liu, S., Dong, G., & Zhu, J. (2016), Effect of elevated CO_2 on the growth and macronutrient (N, P, and K) uptake of annual wormwood (*Artemisia annua* L.). *Pedosphere, 26*, 235–242.

p-ISSN 2012-3612 | e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 13 | Number 1 | pp. 102-113 | 2023

RESEARCH NOTE

Assessment of climate change vulnerabilities of upland vegetable farmers in selected areas in Benguet, Philippines

Priscila C. Dolom[1], Corazon A. Calimag[1], Jean C. Nicmic[1], Pamela Joyce M. Eleazar[1], Ma. Cynthia S. Casin[1], Ma. Magdalena B. Villanueva[1], Diorella Mari T. Garcia[1], Michiko Karisa M. Buot[1*]

[1]*Forestry Development Center, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. Farming is the main livelihood of the people of Benguet Province. This makes them highly vulnerable to climate change hazards as their security and safety depend on unstable agro-climatic conditions. Thus, the climate change vulnerabilities of upland farmers must be assessed to better aid them in coping with the worsening scenes. The study aims to identify such vulnerabilities and determine climate change adaptation and coping measures practiced by upland farmers. Policy interventions that may be relevant to eliminate or lessen vulnerability will also be identified. The typical exposure factors identified in Benguet are landslides, erosion, extreme temperatures, and climate events. The province has a sloping, rugged topography, and intensive land tillage or cropping system. This indicates that the area is sensitive to soil erosion and landslides. The area's soil and water conservation practices are not enough to address heavy rains and drought. The adaptive strategies practiced by upland farmers are using drought and water-resistant crops; water-impounding facilities; greenhouse or crop shelter; tree planting; and planting high-value crops, such as coffee, cacao, lemon, and other fruit trees. Through policy review, comprehensive policy actions were recommended and instituted to address identified vulnerabilities, such as tree planting, information drive, and deputization of barangay officials and volunteers to perform environmental functions. Further, it is recommended that the Sangguniang Panlalawigan, Sangguniang Pambayan, and Sangguniang Pambarangay develop forestry policies with the technical assistance of the Department of Environment and Natural Resources. These recommendations are expected to avert disasters while maximizing the usefulness of the lands and, ultimately, support the upland farmers in their livelihood.

Keywords: adaptivity, exposure, mitigation, policy, sensitivity

Article Information
Received 25 March 2023
Accepted 26 May 2023
Published online 16 October 2023
*Email: mkmbuot@up.edu.ph

INTRODUCTION

It is widely known that climatic patterns are erratic, causing several societal problems. The Philippines is highly prone to climate-related natural disasters like tropical cyclones, floods, and rain-induced landslides (Perez, 2009). He stated that there are observed changes in extreme weather patterns and climate anomalies, such as rising day and night temperatures, shifting typhoon pathways, sea level rise, and decreasing the number of rainy days. The prevention and reduction of the adverse impacts of climate change have been declared a national policy by issuing the Climate Change Act of 2009 (RA 9729). This law identifies local government units (LGUs) as the frontline agencies in formulating, planning, and implementing climate change action plans in their respective areas. It mandates them to consider climate change adaptation as one of their regular functions.

Agriculture is vulnerable to climate change hazards as it is highly dependent on the climate. Dar (2012) listed some of the adverse effects on agriculture due to climate change, such as an increase in water scarcity, increased frequency of drought, increased risk of heat or drought stress to crops and livestock, possible change in the length of the growing period, reduced yield due to physiological changes in crops, and reduction in pesticide effectiveness. This is especially true for upland farming areas in the Philippines, such as the Benguet Province.

Benguet is predominantly an agricultural province susceptible to the hazards of climate change. Most of the labor is in the province's vegetable or cut-flower farming (Reyes *et al.*, 2017). These upland farmers are highly vulnerable as they mostly depend on water availability for their cropping system.

While most upland farmers developed their planting calendar based on climatic patterns observed over time, farmers are finding it difficult to predict the start of the rainy season. The country is experiencing longer drought in one year and longer rainy days in another year. The rainy season is mostly accompanied by strong typhoons, heavy rainfall, and floods that destroy crops and properties.

With agriculture being a primary source of livelihood in Benguet, the impact of climate change highly affects activities in this sector. Hence, the climate change vulnerabilities of upland farmers in Benguet must be assessed. Assessment is essential in the analysis of existing policies. This will then identify policy reforms needed to improve climate change adaptation and mitigation in Benguet. This will ultimately support upland farmers, protect the watershed area, and sustain its use.

Hence, the study specifically aimed to: 1) identify climate change vulnerabilities of upland vegetable farmers in selected areas in Benguet; 2) determine climate change adaptation and coping measures applied by upland vegetable farmers; and 3) evaluate existing policy and regulations to address climate vulnerabilities of upland vegetable farmers in Benguet.

METHODOLOGY

Benguet (**Figure 1**) is comprised of 13 municipalities and one city. The study was implemented in three selected municipalities: La Trinidad, Atok, and Bugias. These areas are considered the salad bowls of the Philippines, as these are the major sources of upland vegetables that supply the requirements of Luzon, particularly Metro Manila.

Moreover, challenges were met in implementing the methods as data was highly dependent on the availability of the respondents and key personnel, the accessibility of some study sites, as well as the natural calamities and hazards that delay travel. These challenges were among the criteria in selecting the study sites aside from the availability of forest lands occupied or tilled by village farmers and the LGU members' willingness to participate in the activity. La Trinidad, Atok, and Buguias were selected since these municipalities passed all criteria. From each of these three municipalities, two barangays were selected: Brgy. Silan and Brgy. Beckel of La Trinidad, Brgy. Cattubo and Brgy. Paoay of Atok, and Brgy. Loo and Brgy. Amlimay of Buguias.

Site description

Benguet Province is one of the six provinces of the Cordillera Administrative Region (CAR). It is the fourth biggest province in the region, accounting for 15.65% of the total land area of CAR. It is predominantly an agricultural province. At least 54% of the labor is in vegetable and cut-flower farming.

Among the three municipalities, Atok has the largest total land area of 21,499 ha with eight barangays, followed by Buguias with an estimated land area of 21,279 ha with 14 barangays, and lastly, La Trinidad, with a total land area of 8,080

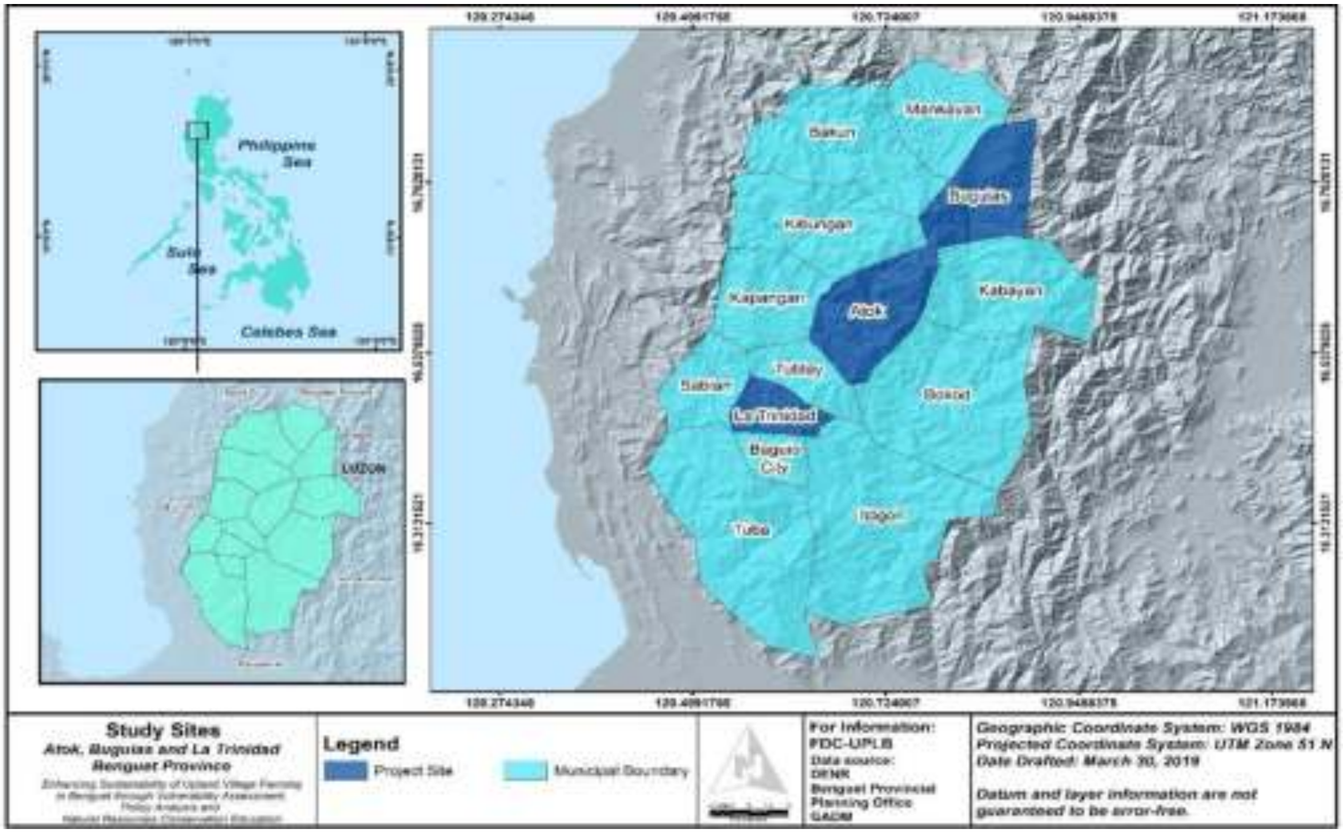


Figure 1. Study sites in Benguet Province.

ha, with 14 *barangays*, and lastly, La Trinidad, with a total land area of 8,080 ha, with 16 *barangays* (La Trinidad Comprehensive Land Use Plan, 2016-2025).

Vulnerability assessment methods

Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007). Data that determined vulnerability were gathered to conduct a descriptive analysis of existing farming practices and crops planted to determine climate change adaptation and mitigation measures applied by the upland vegetable farmers in selected parts of Benguet. The GIZ's Vulnerability Sourcebook was used in the vulnerability assessment (Fritzsche *et al.*, 2017).

The LGUs provided a list of farmers in the barangays from the selected municipalities. From the provided list, participants were selected based on their accessibility and availability.

Site visits, household interviews, key informant interviews (KIIs), and focus group discussions (FGDs) with farmers, local government units (LGUs), the Department of Agriculture (DA), and the Department of Environment and Natural Resources (DENR) were done. Secondary data or reports, such as the Comprehensive Land Use Plan (CLUP), Local Climate Change Action Plan (LCCAP), Forest Land Use Plan (FLUP), Disasters Risk Reduction Management Plan (DRRMP), and Environmental Code and policy issuances, were analyzed as a basis for the primary data.

The information gathered to determine exposure to climate change, such as temperature, rainfall, and extreme climate events, was collected from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), KIIs, and FGDs.

The sensitivity element determines the degree to which a system is adversely or beneficially affected by a given climate exposure. Data or information assessed to evaluate the sensitivity element were data on a natural or physical event, such as slope or topography, the capacity of different soil types to resist erosion, and land cover type. Other data that determined sensitivity were on societal events or human activities, such as cropping systems, tillage, market, and water management. Both information on biophysical and societal components were gathered from PAGASA, DENR, Bureau of Soils and Water Management (BSWM), KIIs, and FGDs.

Adaptive capacity was measured in terms of how the upland vegetable farmers adjust to the potential impacts of climate change. To evaluate this vulnerability, data or information on technology, availability of adaptive strategies or technologies to address climate change impacts (*e.g.*, drought-resistant species, flood-resistant crops, fire-resistant species, and water conservation technologies), institutions, disaster risk preparedness of LGUs, early warning systems, research institutions on climate change, zoning, and climate change adaptation plan were gathered and assessed.

Policy evaluation

Relevant and related national and local policies on climate change adaptation, mitigation efforts and natural resources management, and all available policy issuances on the study sites have been compiled and collated for content and process analysis. A recommendation of policies and identification o f i ssues, c oncerns, a nd problems were accomplished after compiling and analyzing necessary data.

RESULTS AND DISCUSSION

Vegetable farming and flower production are the respondents' primary occupations (**Table 1**). In Atok and Buguias, almost all respondents were engaged in vegetable farming, comprising 65% and 90% of the respondents, respectively. The vegetables grown by the respondents include mustard, spinach, lettuce, cabbage, broccoli, sayote, pechay, carrots, and potatoes. Strawberries were also cultivated by farmers in La Trinidad. The temperate climate in the three areas is ideal for agricultural production.

Cut flower production in La Trinidad is a major source of livelihood. In La Trinidad, more than half (58%) of the respondents were engaged in cut flower production, while 30% were involved in vegetable farming. Agricultural production data from the Municipal Agriculture Office shows that in 2015, cut flower production reached 18,546,965 Mt, surpassing vegetable production (16,108 Mt). Among the popular cut-flowers produced were Malaysian mums, aster, anthurium, alstroemeria, and rose. Coffee production amounted to 29,250 Mt, while strawberry production had 3,135 Mt.

The respondents have been engaged in farming for an average of 17.8 yr. The total household income of the respondents in the three municipalities ranged from PHP 19,000 to PHP 2,160,000, with an average of PHP 306,328 yr-1. Among the three sites, Atok has the highest average annual income of PHP 390,474, while Buguias has the lowest average income of PHP 209,346 yr-1.

Hazards experienced by upland vegetable farmers

Typhoons frequently hit the CAR from June to November during the rainy or wet season. These typhoons brought more rainfall, which caused rain-induced landslides in the region and the municipalities of La Trinidad, Atok, and Buguias in Benguet. The climate in the three municipalities is typical of the first type of climate under the Coronas Classification System, with rainy days from May to October followed by dry spells from November to April in La Trinidad, dry from November to April, and wet from May to October in Atok, and dry season from the December to April and wet season during the rest of the year in Buguias.

Steep mountains and high terrain characterize the topography of the sites. La Trinidad's valley floor elevation is 1,300 m above sea level (m asl). The

Table 1. Occupation of respondents from the three municipalities.

Item	La Trinidad (n=27)		Atok (n=26)		Buguias (n=26)		Total (n=79)	
	No.	%	No.	%	No.	%	No.	%
Vegetable farming	11	30	24	65	26	90	61	60
Flower production	21	58	6	16	0	0	27	26
Employment (Local/abroad)	1	3	3	8	2	7	6	6
Livestock raising	1	3	1	3	0	0	2	2
Others:								
Beekeeping	1	3	0	0	0	0	1	1
Store	1	3	1	3	0	0	2	2
Carpentry	0	0	2	5	0	0	2	2
Food vendor	0	0	0	0	1	3	1	1
Total	36	100	37	100	29	100	102	100

lowest is 500 m asl, while the highest is 1,700 m asl. Amidst the mountain peaks is an approximately 350-ha valley. Atok is predominantly upland, while the remaining 63% covers steep mountain slopes. Buguias has a characteristically rugged and mountainous topography with elevations ranging from 1,300 m to 2,819 m asl.

Due to the rugged topography, geologic composition, and extreme rainfall climate, it is highly vulnerable to geologic hazards, such as landslides, erosions, and ground movements. The Mines and Geo-Sciences Bureau (MGB) studies show that the three municipalities are susceptible to rain-induced landslides, especially in steep slopes where residential developments occurred and as identified in their municipal hazard maps. The province is vulnerable to soil erosion, with at least 16.59% of the total land area expected to experience severe erosion. Almost half, or 46.94% (140,522 ha) of the land is classified under slight erosion, while 31.89% is classified under moderate soil erosion.

Based on the household interviews conducted in Atok, Buguias, and La Trinidad municipalities, all 78 farmer respondents claimed that they were affected by climate change. The effects or hazards that these farmers experienced were recorded in their municipalities' respective management plans (**Table 2**).

Typhoon is the primary hazard in the three municipalities. Rainfall data from PAGASA shows that La Trinidad had lower annual rainfall of 111 mm in 2012 compared to the 30-year average from 1971 to 2000 which is 3877.8 mm This was due to the La Niña and El Niño phenomena. Also, La Trinidad has a relatively cool temperature, with a mean average of 15°C. For the last five years, the average minimum temperature has been at 14.68°C while the average maximum temperature is at 23.6°C.

Large amounts of rainwater-induced landslides destroy crops, houses, and infrastructures, affect transportation and mobility, and negatively affect economic and social activities. Also, many farm lots were destroyed and carried off by flood waters.

La Trinidad and Buguias are also susceptible to flooding. During heavy rains, the Balili River in La Trinidad and its tributaries are filled up with silt from the erosion of slopes from the mountainsides, which causes the water bodies to swell and flood the valley area along the banks of the Balili River and its tributaries downstream. The Agno River in Buguias, where the Loo Valley is located, stretches from Barangay Bangao down to Baculongan Norte, passing through Barangay Loo and Buyacaoan. This valley is susceptible to flooding, particularly during heavy rains and typhoons, as landslides occur along mountain slopes.

Table 2. Hazards experienced in La Trinidad, Atok, and Buguias municipalities, according to their LCCAP and DRRMP.

La Trinidad	Atok	Bugias
· Landslides brought about by continuous rain/typhoon · Floods brought about by continuous rains/typhoons · Earthquake · Forest fir · Drought	· Landslide · Typhoon · Earthquake · Drought · Hailstorm	· Rain-induced landslide/sinking · Flooding · Strong winds · Landslide · Rupture/Shaking · Scarcity of domestic water supply · Scarcity of irrigation supply · Pest and diseases outbreak · Wildfire/Forest fi

Hailstorm is one unique hazard that can be observed in Atok since it has the highest elevation among the three municipalities (the highest elevation is 2,255 m asl). The temperature is generally cold, ranging from 15 to 20 °C, with December to January recording the coldest temperatures (Atok Local Climate Change Action Plan, 2017). During the year's cold months, the municipality experiences very low temperatures reaching 9 °C. This causes frost to settle on the ground resulting in millions of damages to crops but drawing tourists to the town. The community of Buguias, particularly the farmers, has experienced a decrease in water supply for irrigation and domestic use.

Effects of climate change on farming

The following are the effects of climate change on their crop production: 1) lower income, 2) lower volume of harvest, and 3) damages to crops and flowers. These three effects of climate change on farming are interrelated. Damaged crops and flowers due to climate change have resulted in a lower harvest volume and income (**Table 3**).

The FGD results showed the climate change effects on farming: 1) limited and unpredictable water supply due to drought and prolonged rainy season; 2) flooding, which resulted to damage of their farms; 3) landslides and soil erosion which affected their farm soil fertility; and 4) existence of pests and diseases in the area.

Effects of climate change on community and family

Overall, climate change affected the income of Atok and Buguias respondents due to its effects on their crops. Respondents from La Trinidad cited that climate change has affected their health. The number of sick people increased due to more diseases brought about by the extreme change in weather conditions. The decrease in food availability ranked second in the overall effects of climate change experienced by the community and families in La Trinidad and Atok. In Buguias and Atok, damaged roads were ranked second due to frequent landslide occurrences (**Table 4**).

Climate change adaptation strategies practiced by upland vegetable farmers

The effects and hazards of climate change are experienced by all the respondents, as discussed above. Further, the hazard and vulnerability maps were posted in their barangays. Despite the common knowledge of the farmers and residents of their community's highly vulnerable and hazardous areas, they are reluctant to leave as they do not want to abandon their houses and livelihoods. The respondents said that they resort to prayers for their safety. **Table 5** shows the vulnerabilities of the farmers and residents and the corresponding strategies practiced in coping and adapting to the identified vulnerabilities.

In a study conducted by Parao *et al.* (2016), the hazards experienced in Poblacion and Puguis, La Trinidad, Benguet are typhoons, landslides, frost, strong winds, El Niño, La Niña, hailstorms, intense rainfall, flooding, and pests. With these hazards, coping strategies must be applied to sustain the farmers' livelihoods. To address these hazards, coping strategies, such as tunneling, tree planting, water harvesting, hilling up, irrigation, mulching, watering, construction of diversion canals, and spraying fungicides, are practiced respectively.

The recommended list of crops by the regional office of DA-CAR suitable to withstand the climate change effects in Benguet is commonly planted by farmers. However, it has been observed that the recommended timing of planting is not being practiced due to traditional practices and market

Table 3. Effect of climate change on farming.

Item	La Trinidad (n=27)		Atok (n=26)		Buguias (n=26)		Total (n=79)	
	No.	%	No.	%	No.	%	No.	%
Farming practices affected by climate change?								
Yes	27	100	26	100	26	100	79	100
No	0	0	0	0	0	0	0	0
Total	27	100	26	100	26	100	79	100
Effects on farming								
Lower income	19	38	23	32	26	37	94	36
Lower volume of harvest	20	40	25	35	22	31	89	34
Crop damage/ flower damag	11	22	23	32	23	32	80	30
Total	50	100	71	100	71	100	263	100

demand. The following are water-tolerant crops and their recommended planting months: 1) broccoli (October to December; May to June); 2) cabbage (April to June, October to December); 3) eggplant (November to January); 4) garlic and onion (November to January); 5) carrots (July to December); 6) lettuce (October to December), 7) sayote (May to June, November to January); and 8) cauliflower (October to December, June to July).

The priority programs and projects addressing the effects of climate change hazards were also identified through the provincial DRRMP and municipal LCCAP, CLUPs, and local DRRMP. These programs and projects (**Table 6**) reflect the coping or adaptation strategies to be implemented at the provincial and municipal levels in response to climate change.

Policy evaluation

National and provincial level

In response to the global concern about climate change, the Philippine government enacted Republic Act (R.A.) No. 9729, otherwise known as the Climate Change Act of 2009. Further, R.A. No. 10121, or the Disaster Risk Reduction and Management Act of 2010, emphasizes the institutionalization of arrangements, strategies, programs, and activities by LGUs to deal with disaster risks and climate change impacts.

R.A. No. 9729 created the Climate Change Commission (CCC) to formulate the Framework Strategy and Program on climate change at the national level. The framework will be based on climate change vulnerabilities, adaptation needs, and mitigation potential, all in accordance with international agreements. This Act further mandates the CCC to formulate the National Framework Strategy on Climate Change 2010-2022. This framework strategy is committed to ensuring the adaptation of our natural ecosystem and human communities to climate change. This will serve as a guide to preparing the Provincial Development Plans, Provincial Physical Framework Plan, and at the local level, the Comprehensive Land Use Plan and Comprehensive Development Plan. The Framework shall also serve as a basis for preparing the NCCAP, a key component for developing the LGUs' LCCAP.

These laws provide, among others, LGUs as frontline agencies in formulating, planning, and implementing climate change action plans in their respective areas. The formulated LCCAP shall be consistent with the provision of the Local Government Code (R.A. 7160), the Framework, and the NCCAP. It enhances inter-local government unit collaboration in the conduct of climate-related activities.

Table 4. Effects of climate change on community and family.

Items	La Trinidad (n=27)		Atok (n=26)		Buguias (n=26)		Total (n=79)	
	(n=27)	%	(n=26)	%	No.	%	No.	%
Increase in the number of sick people/more diseases	18	43	14	18	12	16	44	22
Decrease in food availability	9	21	20	26	9	12	38	24
Less income/money for expenses	2	5	22	28	27	35	51	26
Yellowing of leaves of plant/plants are destroyed	5	12	0	0	3	4	8	4
Roads are damaged	4	10	20	26	15	19	39	20
Lower harvest of flowers/crop	1	2	0	0	4	5	5	3
Pests and diseases of plants	1	2	0	0	0	0	1	1
Too much heat causes flowers to bloom even if still smal	1	2	0	0	0	0	1	1
When the temperature is low, flowers have difficulty to blo	1	2	0	0	0	0	1	1
Increase in natural disaster	0	0	0	0	1	1	1	1
Change of jobs	0	0	0	0	3	4	3	2
Increase of migration	0	0	0	0	1	1	1	1
No employment	0	0	2	3	1	1	3	2
Threatens purity of water	0	0	0	0	1	1	1	1
Total	42	100	78	100	77	100	197	100

Table 5. Effects of climate change on community and family.

Vulnerability	Adaptation strategy
Changing rainfall patterns	Tree planting, alternative livelihood, change of crops or concentrate on crops that withstand climate change effects, construction of greenhouse and crop shelter, adjustment of cropping calendar
Extreme hot and cold temperatures	Change of crops or concentrate on crops that withstand climate change effects, adjustment of cropping calendar
Unpredictable strong typhoons, winds, and monsoon rains	Change of crops or concentrate on crops that withstand climate change effects, construction of greenhouse and crop shelter
Drought and water scarcity	Water impounding, rainwater harvesting
Drastic temperature changes	Change of crops or concentrate on crops that withstand climate change effects
Flood occurrence	Tree planting, planting of bamboo, riprapping
Landslide	Riprapping, IEC, early warning system
Low level of soil fertility	Crop rotation, no mono-cropping practices, use of chicken dung as fertilizer, organic farming
Pests and diseases	Change of crops or concentrate on crops that withstand climate change effects, construction of greenhouse and crop shelter, a local ordinance prohibiting the use of inorganic pesticides
Forest fire	Tree planting, IEC, fire brigade, local ordinance

In Benguet, Resolution No. 02-2016 was signed by the Sangguniang Panlalawigan, otherwise known as "A Resolution Approving the Updated Provincial Disaster Risk Reduction and Management Plan (PDRRMP), CY 2013-2017." The PDRRMP embodies the strategies, programs, projects, and activities consistent with the mitigation, preparedness, response, and rehabilitation pillars of disaster risk reduction and management and climate change adaptation action plan, including a contingency plan and an Incident Command System consistent with standard operating in every scenario. Considering that the province of Benguet has adopted the PDRRMP, La Trinidad, Atok, and Buguias municipalities prepared their LCCAP.

Municipal level

In line with the LCCAP of La Trinidad, Barangay Shilan prepared its DRRMP for CY 2017-2020, approved by the Office of Sangguniang Barangay as Resolution No. 16, Series of 2017. The four-year DRRMP aimed at strengthening its capacity with partner stakeholders to build disaster-resilient communities. This includes institutionalization arrangements and mechanisms to reduce disaster risks, such as projected scenarios, adaptation and mitigation of climate risks, and enhancing disaster preparedness and response capabilities at the community level. Through this, a Barangay Disaster Coordinating Committee was formed.

The Buguias LCCAP (2016 to 2021) was used as a guiding tool by the local climate change managers and community people to mitigate climate change effects and increase the community's resilience. The LCCAP of Buguias identified the different climate change vulnerabilities of the municipality, the disaster risk reduction and management programs, projects and activities, the disaster preparedness and response programs, projects and activities, and the social services key activities and description. To implement the LCCAP, various strategies such as 1) building adaptive capacity; 2) creating of functional climate change adaptation core team and technical working group; 3) setting guiding principles for adaptation; and 4) other support systems were identified.

The Atok LCCAP was patterned from the NCCAP and PDRRMP, which have the following work priorities and target outcomes such as food security, water sufficiency, ecosystems and environmental stability, human security, climate-smart industries and services, as well as knowledge and capacity development. Vulnerability and adaptation assessment covers climate-related hazards and their impacts on the municipality; the elements, sectors, and institutions exposed to climate change hazards; and the exposure analysis and influence diagram. Each municipality created an LCCAP with policies on conserving and protecting environmental and natural resources and climate change adaptation and mitigation strategies. However, about 45% of the respondents said that the barangay officials implemented these policies. Each municipality created an LCCAP with policies on conserving and protecting environmental and natural resources and climate change adaptation and mitigation strategies. However, about 45% of the respondents said the barangay officials implemented these policies. Moreover, according to field interviews and the household survey, few respondents knew these policies (**Table 7**). Some answered that the barangay-level policies were implemented by the national government, DENR officials, private forestland owners, Philippine National Police (PNP), and LGUs.

All respondents from La Trinidad know policies and local ordinances related to the conservation and protection of natural resources (Table 7). Buguias and Atok (73%) respondents answered negatively. All the respondents from La Trinidad knew about the policy on the logging ban. Atok respondents have knowledge of the following policies: 1) bantay gubat; 2) road landscaping; 3) patrol of forest areas; 4) proper waste disposal; 5) kijowan (Ibaloi practice on conservation); and 6) existing national policies.

The following local ordinances were recommended by the key informants to address climate change adaptation and mitigation: 1) plant trees and protect the environment; 2) stop illegal logging activities; 3) stop burning the farms after harvest; 4) educate the young generation the importance of maintaining the environment biodiversity; 5) practice waste segregation; 6) establishment of drainage system; and 7) strict implementation of policies for compliance of all.

Based on the FGD results, the following policies were recommended: 1) adoption of alternative energy sources; 2) enactment of the local ordinance on climate change; 3) practice of agroforestry system/reforestation; 4) adaptation of organic agriculture; 5) cancellation and discontinuing the issuance of land title or tax declaration in watershed areas and communal forests; 6) use of crops that are suited to drought and periods of La Niña; and 7) provision of enough budget/funding in the implementation of environmental programs.

Table 6. Priority programs and projects based on the study sites' LCCAP and CLUP.

Buguias	Atok	La Trinidad
1. Production support services • Promotion of good agricultural practices, good manufacturing practices, and organic agriculture • Farmers' training • Establishment and maintenance of technology and demonstration farms • Maintenance of composting facilities • Maintenance and operation of soils laboratory 2. Enhancement of production through support activities • construction of greenhouses • farm mechanization • multi-tiller hand tractor • grass shredders/chopper • purchase of Micro Tiller • coffee post-harvest equipment (depulper, dehuller) 3. Promotion and development of Organic Agriculture • establishment of soil and organic farm inputs laboratory • establishment of the composting center and vermiculture facilities with equipment (grass shredder, etc.) 4. Extension, support, education, and training services • support to Municipal Agriculture and Fishery Council and • support to JAEC projects on SAVERS technology	1. Production support services • Procurement and distribution of planting materials/seeds/seedlings • Production and distribution of planting materials • Establishment of production support facilities • Greenhouses • Nurseries • Seed potato storage • Farm machinery and equipment 2. Research, Extension Support, Education, and Training • research/technology dissemination • crop protection • soil and water conservation • Organic agriculture • Good agricultural practices • support to the nutrition program • safe vegetable project and marketing resources • market promotion and development • credit facilitation • Rural Based Organization (RBO) strengthening • Farmer's Information and Training Service (FITS) Center • sisterhood program/ young farmers exchange program 3. Plan and policy formulation, advocacy, and M&E • Planning and information services • Support to agricultural-related council activities 4. Agri-infrastructure support services Validation/Provision/Establishment • Irrigation facilities • Production support facilities • Farm-to-market roads • Postharvest and processing facilities Other infrastructure support facilities	1. Construction of overpass and flyover Kilometer 5 and Buyagan National Road Junction 2. Improvement of alternate roads 3. Improvement of La Trinidad drainage system (Valley Floor) 4. Comprehensive La Trinidad Sewerage and Septage System 5. Comprehensive rehabilitation of the Balili River 6. Pico-Capjaran-Toyong- strawberry farm-Bugayan access road 7. Eco-tourism development and protection of watersheds/communal forests (Poguis, Alapang, Alno, Shilan, and rehabilitation of Busol Watershed) 8. Diversion Road (along Balili River) 9. Km5- Tebteb, Balili- Tawang Road 10. DOST- Cruz Bypass Road 11. Comprehensive Flood Control System for La Trinidad Valley 12. Bineng-Tuel (Tublay)-Alno Road 13. Eviction of illegal occupants within the municipal loots, barangay cemeteries, and communal forests/watersheds 14. Construction/Establishment of Municipal Abattoir 15. Construction/Establishment of multi-level parking 16. Automated guided transit 17. Renewable energy/ waste to energy for SWM

CONCLUSIONS AND RECOMMENDATIONS

The vulnerability of the Benguet province was assessed, and the typical exposure factors identified are landslides, erosion, extreme temperatures, extreme climate events such as heavy rain and typhoons, and drought. The salient hazard of climate change felt in the province through its effects on their community, family, and farming was the extreme weather condition or climate events.

The province is characterized by sloping and rugged topography and intensive land tillage or cropping system; thus, it is sensitive to soil erosion and landslide. Moreover, most farmers are engaged in crops and cut flower production. Their farms are mostly located in sloping and steep areas, making them vulnerable to such hazards. The area's soil and water conservation practices are not enough to address heavy rains and drought.

Table 7. Knowledge of policies and local ordinances related to the conservation and protection of natural resources.

Item	La Trinidad (n=27)		Atok (n=26)		Buguias (n=26)		Total (n=79)	
	No.	%	No.	%	No.	%	No.	%
Knowledge of policies?								
Yes	27	100	7	27	0	0	34	43
No	0	0	19	73	26	100	45	57
Total	27	0	26	100	26	100	79	100
Kind of policies								
Log ban	27	100	0	0	0	0	27	79
Bantay gubat	0	0	1	14	0	0	1	3
Road Landscaping	0	0	1	14	0	0	1	3
Patrol forest areas	0	0	1	14	0	0	1	3
Proper waste disposal/management	0	0	2	29	0	0	2	6
Kijowan	0	0	1	14	0	0	1	3
National policies	0	0	1	14	0	0	1	3
Total	27	100	7	100	0	0	34	100
Knowledge of who implements this policy								
National government	16	37	0	0	0	0	16	31
Barangay official	17	39	6	86	0	0	23	45
DENR/Foresters	9	20	0	0	0	0	9	18
Owner of the forest/land	1	2	0	0	0	0	1	2
PNP	1	2	0	0	0	0	1	2
LGU	0	0	1	14	0	0	1	2
Total	44	100	7	100	0	0	51	100

To address the climate change vulnerabilities of the upland farmers in Benguet, the following adaptive strategies were employed: use of drought and water-resistant crops or species; water impounding facilities; greenhouse or crop shelter, planting of high-value crops, such as coffee, cacao, lemon, and other fruit trees. The three municipalities' provincial DRRMP, the LCCAP, and CLUP also state coping and adaptation strategies to address climate change. Through the policy evaluation, it is found that the three municipalities were equipped through their provincial and local plans. However, the implementation of the plans and knowledge and awareness of the farmers should be strengthened.

Based on the study's findings, it is recommended to 1) institute comprehensive policies and measures to address vulnerabilities. This is to mitigate or avert disasters and reduce the risks of disasters; 2) conduct tree planting in areas that need rehabilitation as identified by DENR, LGUs, and other concerned offices; 3) conduct information drive (information, education, communication) such as creation or construction of warning signages in hazardous areas in the barangay; 4) deputize barangay officials and non-disabled residents or volunteers by the DENR or Deputized Environment and Natural Resources Officers (DENROs) subject to specific rules and regulations to perform environmental functions, including forest protection; 5) facilitate orientation and training to equip them with the proper authority to apprehend, confiscate and file charges against violators in accordance to DENR Administrative Order No. 2008-22; 6) DENR, LGUs, and PNP including other para-military units shall coordinate closely on forest protection and enforcement of forest laws and regulations.

With the implementation of R.A. 7160, it is recommended that the Sangguniang Panlalawigan, Sangguniang Pambayan, and Sangguniang Pambarangay shall develop forestry policies with technical assistance from DENR. They shall prescribe policies ensuring good governance in forest management through transparency, due diligence and accountability, predictability, and participation of different sectors and stakeholders in the decisions and actions to govern the environment and natural resources.

LITERATURE CITED

Atok Communal Forest Management Plan Technical Working Group. (n.d.). *Atok Communal Forest Management Plan*. Atok, Benguet.

Atok Comprehensive Land Use Plan Technical Working Group. (n.d.). *Atok Comprehensive Land Use Plan*. Atok, Benguet.

Atok Local Climate Change Action Plan Technical Working Group. (n.d.). *Atok Local Climate Change Action Plan*. Atok, Benguet.

Buguias Comprehensive Land Use Plan Technical Working Group. (n.d.) *Buguias Comprehensive Land Use Plan 2013-2022*. Buguias, Benguet.

Buguias Local Climate Change Action Plan Technical Working Group. (n.d.). *Buguias Local Climate Change Action Plan 2016-2021*. Buguias, Benguet.

Buguias Municipal Disaster Risk Reduction Plan Technical Working Group. (n.d.) *Buguias Municipal Disaster Risk Reduction Plan*. Buguias, Benguet.

Dar, W. D. (2012). *Climate Change Impacts and Adaptation in the Semi-Arid Tropics*. Paper presented at the International Conference on Climate Change Impacts and Adaptation for Food and Environmental Security, SEARCA Auditorium, UPLB, Los Banos, Laguna, Philippines, November 21, 2012.

Fritzsche, K., Schneiderbauer, S. ,Bubeck, P., Kienberger, S., Buth, M., Zebisch, M., & Kahlenborn, W. (2017). *Vulnerability Sourcebook: Concept and Guidelines for Standardized Vulnerability Assessments*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Germany.

IPCC [Intergovernmental Panel on Climate Change]. (2007). *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M. L., Canziani, O. F., Palutikof, J. P. van der Linden, P. J., and Hanson, C. E. (eds.), Cambridge University Press, Cambridge, UK, 976 p.

La Trinidad Climate Change Technical Working Group. (n. d.). *La Trinidad Climate Change Action Plan 2016-2025*. La Trinidad, Benguet.

La Trinidad Comprehensive Land Use Plan Technical Working Group. (n. d.). *La Trinidad Comprehensive Land Use Plan*. La Trinidad, Benguet.

La Trinidad Disaster Risk Reduction Management Plan Technical Working Group. (n. d.) *La Trinidad Disaster Risk Reduction Management Plan*. La Trinidad, Benguet.

La Trinidad Forest Land Use Plan Technical Working Group (n. d.) *La Trinidad Forest Land Use Plan*. La Trinidad, Benguet.

Parao, M., Pablo, J. P., Wagan, A. M., Garcia, J. N. M., & Medina, S. M. (2016). Climate change vulnerability assessment in selected highland areas of Benguet: An application of VAST-Agro Tool. *Mountain Journal of Science and Interdisciplinary Research*. Benguet State University. <http://journals.bsu.edu.ph/index.php/BRJ/article/view/14/218>.

Perez, R. T. (2009). *Climate Change in the Philippines*. Paper presented at the Symposium on the Economics of Climate Change in SE Asia, De La Salle University, November 17, 2009.

Reyes, C. M., Domingo, S. N., Agbon, A. D., & Olaguera, M. D. C. (2017). *Climate Sensitive Decisions and Use of Climate Information: Insights from Selected La Trinidad and Atok, Benguet Agricultural Producers*, PIDS Discussion Paper Series, No. 2017-47, Philippine Institute for Development Studies (PIDS), Quezon City.

ECOSYSTEMS & DEVELOPMENT JOURNAL
Guide for Authors

The E&D Journal welcomes research articles, policy papers, and essays on emerging issues and concerns on ecosystems, forestry, and natural resources.

Accepts articles on the broad subject of the interactions of human and natural systems, including but not limited to the following fields: advocacy, agroforestry, biodiversity, climate change adaptation and mitigation, community-based forestry and natural resources management, community participation, conflict management, development communication, disaster risk reduction, ecosystem management, extension education, integrated approaches to natural resources management, forest management, conservation & stewardship, land use assessment and planning, policy studies, products development, ridge-to-reef approach, upland development, soil and water conservation, sustainable development, and watershed management.

Originality and Recency

1. Articles must be new, original, unpublished, and should not have been published in or submitted to other journals or publications for consideration.
2. Articles should deal with findings and data not older than five years and may include a discussion on the implications of the findings for natural resources and ecosystems development.
3. Papers presented in conferences may be considered, but these should be rewritten as journal articles.

Recommended Format

1. A1. Articles should be processed in Microsoft® Word 2007/2010 (docx), typed double-spaced in A4 sized paper, 12-points Palatino Linotype font, in third person point of view, and in American English.

2. Articles should not exceed 25 pages (including the abstract, tables, figures, maps, and appendices) and must include the number of pages using the automatic numbering function.

   The manuscripts should contain the following sections:
   a. **Title** – Specific, concise, and less than 20 words. All words, except the first word, except proper nouns, should be in lower case letters.
   b. **List of authors, affiliations, and email addresses** – Full names of all authors, designation, and affiliations (department, university or organization, city, and country) must be provided. Underline the corresponding author, and include the official email address.
   c. **Abstract** – A summary of the article not exceeding 300 words. No abbreviations, no acronyms, and the content should define the topic and problem. The abstract must present the hypothesis, articulate methodology, and salient findings.
   d. **Keywords** – Not more than five suitable keywords or phrases, separated by commas. Keywords should not repeat words already in the title.
   e. **Introduction**- Provides the context of the article, written understandably for readers who are not experts in that field.
   f. **Methodology** – Should specify all the techniques, equipment, and materials used, including study area details and limitations.
   g. **Results and Discussion** – It should contain the proposed ideas/theories, significant results, and related discussions. Highlight the main findings while ensuring continuity of the discussion.
   h. **Conclusion** – Summary of findings, importance, gaps, and recommendations for further research.
   i. **Literature Cited** – Should contain at least 20 references, arranged alphabetically, and published within 10 years. Make sure the list is complete and matches the citations in the article.
   j. **Acknowledgments** – Optional and usually includes names of people and/or organizations who contributed to the work but do not fit the criteria to be listed as authors. Include at most five sentences.

3. The article (including tables, figures, photos, maps, and appendices) should be submitted electronically to edjournal@up.edu.ph.
   a. Scanned line drawings should be digitized with a minimum resolution of 800 dpi relative to the final figure size. For digital halftones, 300 dpi is sufficient.
   b. Use a 16-bit CMYK or RGB image for color illustrations and photographs. It could be stored in TIFF, JPEG, PNG, or BMP format. Please indicate the compression software used if the image files are large and compressed before submission.

4. Article with multiple authors need to accomplish the co-authorship agreement form.

Other Details

1. Use the metric system for data that require units of measure.
2. Use italic type for scientific names, vernacular names of organisms, and local or native terms.
3. Use en-dash '–' for span or numbers such as page ranges, size ranges, elevational ranges (*e.g.*, 10–15 m tall, 300–500 m elevation), or phenology (*e.g.*, fruiting May–July).
4. Use 'elevation' (the height of a surface on earth above sea level) when referring to a mountain or other geological features.
5. Use boldface for textual emphasis and mathematical formulas.
6. Submit all figures in a separate folder.
7. Maps should be submitted in digital format (jpeg or tiff). Map size and resolution should be enough to be printed in A1 or larger paper size.
8. Use the table functions of Microsoft® Word, not spreadsheets, to make tables.
9. Use the equation editor of Microsoft® Word or Math Type for equations.
10. When applicable, equations and scientific notation should be written in exponential form.
11. Use tab stops or other commands, not the space bar, for indents.
12. Use left paragraph alignment only (do not justify lines; allow the automatic line wrap to function).
13. Use tab for paragraphs (do not automatically indent any lines).
14. Use two-line spacing throughout (do not automatically insert extra space before or after paragraphs).

Citing References

1. Follow the APA (American Psychological Association) style to cite sources.
2. All authors cited in the text should be listed in the Literature Cited section.
3. Self-citations should not exceed three.
4. Avoid end notes.

Review Process

Manuscripts go through a double-blind peer review. The author should exert an effort not to reveal his or her identity during the review process.

Please send your manuscript, along with a cover letter to:

The Editor-in-Chief
Ecosystems & Development Journal
Office of the Coordinator for Research, Extension, and Linkages
College of Forestry and Natural Resources, University of the Philippines Los Baños
College, Laguna, Philippines
Email: edjournal@up.edu.ph

Table of Contents

RESEARCH ARTICLE

RESEARCH NOTE