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Land cover change and ethnoecological practices in Forest Management Unit XXV, North Sumatra, Indonesia

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Abstract. *Samsuri, Zaitunah A, Samsura A, Marbun HY. 2025. Land cover change and ethnoecological practices in Forest Management Unit XXV, North Sumatra, Indonesia. Biodiversitas 26: 4545-4556.* Forest management unit (FMU) is important site-level managers included in the sustainability of productivity. This concept is closely related to land tenure conflicts, which are influenced by community livelihood, local knowledge, traditional customs, environmental capacity, and local institutions. The dynamics of change in local knowledge, traditional customs, and population growth can increase the need for land and negatively impact biodiversity. Therefore, this research aims to (i) analyze land cover change and indigenous local knowledge, and (ii) examine the correlation between land cover change with community ethnoecological practices in FMU, North Sumatra. Landsat 5 and 8 Operational Land Imager (OLI) images were used to identify land cover change. Furthermore, the contingency coefficient correlation method was used to examine the relationship between land cover change and ethnoecology. The results showed that 10 land cover categories were identified, including water bodies, forest, paddy field, rubber estate, shrubs, bare land, mangroves, rubber, oil palms, and mixed garden. Rubber plantations experienced the most significant land area loss between 2001 and 2020, decreasing by 1,918.8 hectares. Meanwhile, mixed gardens reported a substantial gain of 6,171.8 hectares. The interviews identified 6 ethnoecological elements of the community, namely indigenous knowledge, medicinal plants, wood use, wild animal hunting, non-timber forest products, and traditional events. There was no significant correlation between land cover and community ethnoecological change. Despite the absence of a direct statistical relationship, these persistent practices provide crucial indirect support for in-situ biodiversity conservation within the managed forest landscape. In this context, the conversion of agricultural land and the destruction of forest in FMU areas must be addressed. The community indirectly supports the concept through planting and maintaining local species in mixed gardens. The continued cultivation of native species in community-managed gardens contributes indirectly to biodiversity conservation in FMU area despite the lack of significant correlation.

Keywords: Batang Toru ecosystem, ethno-ecological, forest management unit, land cover change, Landsat image

Abbreviations: CSA: Centre of Statistics Agency, FMU: Forest Management Unit, NTFP: Non-timber forest product, PFMU: Production Forest Management Unit

INTRODUCTION

Forest ecosystems are critical global assets, providing indispensable ecosystem services, harbouring the majority of terrestrial biodiversity, and supporting the livelihoods and cultural practices of millions of people worldwide (Brooks 2002). Despite their immense value, tropical forests, particularly in Southeast Asia, face unprecedented threats from anthropogenic activities. Indonesia, a nation synonymous with megadiversity, has experienced some of the highest rates of tropical deforestation globally, primarily driven by agricultural expansion, logging, and infrastructure development (Hansen et al. 2013; Margono et al. 2014; Abood et al. 2015). This large-scale conversion of forest cover to other land uses not only contributes significantly to global carbon emissions but also precipitates a dire loss of habitat, pushing countless endemic and endangered species toward extinction and undermining the ecological functions that sustain both natural and human systems (Wich et al. 2016; Dislich et al. 2017). This loss threatens critical ecosystem services and biodiversity hotspots (Brooks et al. 2002; Sodhi et al. 2004).

In response to the complex challenges, the Indonesian government has implemented various policy instruments aimed at achieving a sustainable balance between conservation and development. A cornerstone of the strategy is the established of the Forest Management Unit (FMUs), designed as an integrated landscape management institution to balance conservation, sustainable production, and community welfare at the local level (Ministry of Forestry 2007; Moeliono et al. 2014; Sahide et al. 2016). The FMU policy represents a significant shift towards decentralised forest governance, aiming to provide a more contextualised and effective framework for managing forest resources.

While the biophysical and ecological aspects of land cover change are well-documented through remote sensing and geospatial analysis, their intersection with socio-cultural systems is less understood. The transformation of the landscape invariably intersects with the human communities that inhabit and depend upon it. Ethnoecology, which explores

the intricate relationships between human societies and their environment, provides a critical lens for this (Toledo 1992; Martin 2004). It posits that indigenous and local knowledge systems, encompassing practice related to medical plants, non-timber forest products (NTFPs (Rochmayanto 2023), and traditional land use, are vital for sustainable resource management and biodiversity conservation (Berkes et al. 2000; Gomez-Baggethun 2013; Adom et al. 2016). However, the dynamics between rapid landcover change and the resilience of these ethnoecological practices remain a significant knowledge gap, particularly within the framework of state-mandated forest management like FMUs. This potential disconnect between landscape transformation and cultural resilience represents a significant gap in our understanding of socio-ecological systems, particularly within the novel governance context of FMUs.

The study focuses specifically on Forest Management Unit XXV (FMU XXV) in North Sumatra. This site was selected due to its strategic conservation importance; it encompasses part of the Batang Toru Ecosystem (BTE), a known habitat for critically endangered species such as the Tapanuli orangutan (*Pongo tapanuliensis* Nurcahyo, Meijaard, Nowak, Fredriksson & Groves, 2017) and Sumatran tiger (*Panthera tigris* subsp. *sumatrae* Pocock, 1929) (Haidir et al. 2008; Nater et al. 2017). Simultaneously, the area supports local communities whose livelihoods and cultural practices are deeply intertwined with the forest. The coexistence of high conservation value and significant anthropogenic pressure makes FMU XXV an ideal case to study to investigate the interplay between ecological change and cultural resilience.

Numerous current studies effectively document the direct negative impact of land cover change on ecological knowledge. However, this assumption overlooks the potential for community adaptation and cultural resilience, particularly within a government landscape like Indonesia FMUs. While FMUs are established to integrate conservation and community welfare, there is a critical gap in understanding whether these managed landscapes actually decouple environmental change from cultural erosion. Previous research in Indonesia has often examined land cover change or ethnoecological knowledge in isolation. Few studies have empirically investigated the correlation between quantitative land cover change and qualitative shift in community-based ethnoecological practice within a managed forest landscape. Therefore, this study aims to bridge this gap by (i) quantifying land cover change in FMU XXV over 20 years (2001-2020); (ii) documenting and analyzing contemporary community ethnoecological practices; and (iii) statistically assessing the correlation between observed land cover change and these practices. The finding will provide critical insight for developing more nuanced and culturally sensitive conservation strategies within the FMUs framework, ensuring they effectively support both ecological integrity and community.

MATERIALS AND METHODS

Research area

This research was conducted in the FMU XXV area of Sumatra Utara Province from January to April 2021. FMU XXV North Sumatra was geographically located between 1°42'24.3"-1°28'21.3" N and 98°26'45"-98°40'7.9" E in Sumatra Island, Indonesia (Figure 1), covering an area of 6,008 km^2 (FMU XI Pandan 2015).

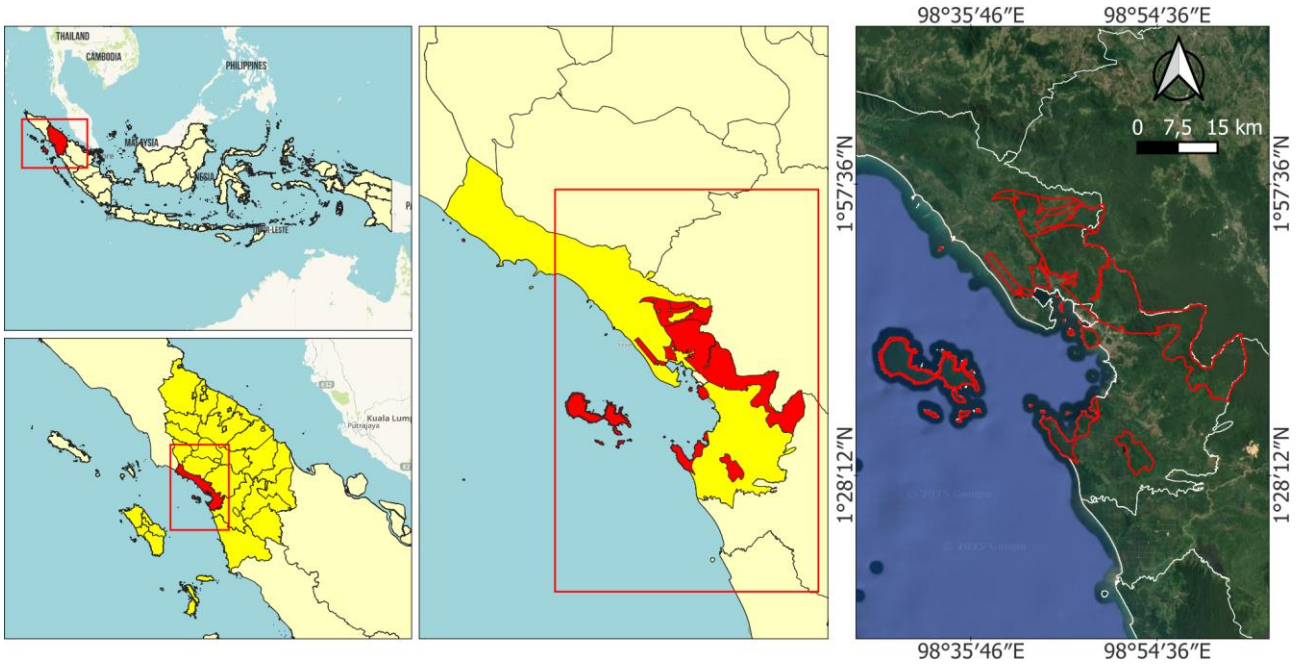

Figure 1. Research area in FMU XXV area, Tapanuli Tengah, Sumatra Utara Province, Indonesia

Tool and material

This research used Global Positioning System (GPS), stationery, a tally sheet, and a camera to collect data. The data analysis tools used were ArcGIS (ArcMap) 10.3 for spatial analysis, ERDAS Imagine 9.1 for image analysis, SPSS Statistics 20.0 for correlation analysis and Microsoft Excel for data tabulation. Primary data were collected directly from measurements and field observations, while secondary data were publicly available and owned by the government. The materials used were obtained from other sources and ground check data, such as 2001, 2010, and 2020 Landsat images, as well as working area and administration maps. Landsat 5 images from 2001 and 2010, and 8 OLI images from 2020, were downloaded from the https://earthexplorer.usgs.gov/ (United States Geological Survey/USGS) website.

Historical satellite images related to the implementation of Indonesian Forestry Regulation No. 41/1999 were utilized in the early 2000s and at the beginning of FMU establishment in 2010. The initial implementation of the 1999 law, which delegated forest management authority to regional governments, significantly eased community access to forest resources. The implementation of the law proved problematic since the increased accessibility of forest resources (Nurkin 2006) led to degradation and fragmentation (Samsuri et al. 2014; Rijal et al. 2016; Aabeyir and Agyare 2021). The central government created a forest management unit (FMU) at the location level to address the issue. FMU worked with local communities to decrease degradation by improving forest monitoring and utilization (Suwarno 2015). However, FMU was limited as an administrator toward the end of 2021.

Data analysis

Land cover change analysis

The supervised method classified the satellite image data into land cover classes. The method used was the maximum likelihood in ERDAS Imagine 9.1. Classification of Landsat images in 2001, 2010 and 2020 adopted the Sumatran monogram (Ministry of Environment and Forestry 2020). The Sumatra Monogram provides a visualization of various land covers in Sumatra, serving as an interpreter's guide for classifying land cover in satellite images.

Land cover change analysis was performed by overlaying land cover maps for 2001, 2010, and 2020 using ArcGIS 10.3. A classification accuracy test was conducted to evaluate land cover classification accuracy determined based on the training area. Subsequently, the accuracy was calculated using a contingency or confusion matrix. The error or confusion matrix was a square matrix containing the number of pixels used in the classification (Poonia 2022).

Ethnoecological analysis

Ethnoecological data were collected from the selected respondents. Meanwhile, respondents were selected using the purposive sampling method or intentionally by setting criteria from the eligible population to provide information and answer research problems (Amrul et al. 2019). The sample size was determined using Slovin's formula (Sevilla et al. 2003) with a population (N) of 6,247 heads of families, at a 10% margin of error (e):

$$n = \frac{N}{Nd^2 + 1}$$

Where: n: sample size, N: population size, d: sampling error estimation (10%).

Based on the calculation using the Slovin formula, the number of respondents was determined to be 100 individuals. Respondents or sampling units adopted were heads of households who directly and indirectly used forest flora and fauna in the research area. Additionally, the interview with the village official found that the variable ethno-ecology included the traditional practices of hunting, tree cutting, farming, collecting medicinal plants from the forest, and participating in traditional ceremonies. The data collection method used in this research was in-depth interviews. Data from in-depth interviews were transcribed and analysed using thematic analysis (Braun and Clarke 2021). The ethnoecology data included the frequency and results of traditional hunting activities, the frequency and volume of flora use, and the sustainability of customs. In the interviews, important ethnoecological functions were identified to analyse the relationships between variables (Okoko et al. 2023). According to Miles et al. (2014), analysis consisted of data reduction, presentation, and conclusions performed simultaneously.

Correlation analysis

A correlation analysis was conducted to determine the relationships between the variables. Correlation coefficient contingency analysis was used, and the hypotheses (Creswell and Creswell 2018) were examined. To facilitate statistical analysis, the nominal categorical variables for both land cover change and ethnoecological practices were transformed into dichotomous dummy variables, coded as 1 for the presence of change and 0 for the absence of change (Agresti 2018; Field 2018). This coding scheme allows for the computation of correlation coefficients suitable for categorical data. The strength and significance of the association between these dichotomous variables were then determined using the Phi (φ) coefficient (Akoglu 2018). The strength of the association was interpreted using the Phi (φ) coefficient, where values close to 0 indicate a weak or no association, and values approaching.

The use of binary coding for analysing change in socio-ecological systems is an established method in human ecology (Jones et al. 2008). Following this approach, we coded our variables for change as 1 and no change as 0. This analysis method was also used by Tesfahunegn (2019) to examine farmers' perceptions of land degradation in northern Ethiopia. Contingency coefficient correlation was used as the statistical analysis method for categorical or nominal variables (Kara 2022). The association between categorical variables was quantified and assessed without making any assumptions about the underlying data distribution to determine the significance and strength of the relationship.

RESULTS AND DISCUSSION

Land cover change dynamics (2001-2020)

The supervised classification of satellite imagery result maps for 2001, 2010, and 2020 resulted in an overall accuracy of 83.11, 82.86, and 89.98%, and a kappa coefficient for all years is 82.31, 82.64, and 81.93%. The analysis revealed a significant change in land cover within FMU XXV over the two-decade period (Figures 2, 3 and 4). The most notable change was the conversion of forest areas to other land cover types. Primary and secondary forest cover decreased from 39.755,88 ha in 2001 to 38.206,84 ha in 2020, representing a net loss of 1,549.04 ha (Table 1). Concurrently, areas classified as mixed garden, agricultural land, and settlement area showed a substantial increase.

The largest land cover change of 204.77% occurred in rice fields between 2001 and 2010. This increase in paddy fields was in line with the population of Central Tapanuli (1.85%) from 2001 to 2010 (CSA of Tapanuli Tengah 2010). The most significant land cover class change observed was the conversion from rubber plantations to mixed gardens, accounting for 17.3%. The shift from rubber estates to mixed gardens occurred when the areas became residential, with trees planted in the new yards.

The forest declined by 1,549.05 hectares between 2001 and 2020. Land clearing for agriculture and palm oil plantations was also assumed to cause a decline. Forest was described as a potential natural resource profitable for individuals who depend on natural products. In the FMU XXV area, forest continued to experience an average decline of 0.013% yearly between 2001 and 2020. The condition underwent rapid and dynamic changes following regional development, as viewed from the perspective of vegetation cover. Sumatra Utara development statistics showed that economic growth in 2010 was 6.8%, higher than the average national growth of 6.2% (CSA of Tapanuli Tengah 2010). According to Putri et al. (2019), the development process was accompanied by population growth and increased living needs.

Population growth affected land use change due to complex interactions among physical, biological, economic, political, and social factors (Zhang and Xie 2019). The population of the 15 subdistricts in the FMU XXV area was 250,224 in 2010 (CSA of Tapanuli Tengah 2010) and increased by 40,982 to 291,206 in 2020 (CSA of Tapanuli Tengah 2020). Population growth increased basic human needs, including food, housing, and other public facilities. The settlement expanded in the FMU XXV area, which is covered by residential land. This area showed a consistent increase, from 1,103.86 ha (1.84%) in 2001 to 2,453.09 ha (4.08%) in 2020, with an intermediate value of 1,506.74 ha (2.51%) in 2010. Figure 2 shows the data on the percentage of land cover change in FMU XXV for 2001 and 2010.

Table 1. Land cover distribution in 2001, 2010, and 2020 of FMU XXV, North Sumatra

Land cover	2001		2010		2020	
	Ha	%	Ha	%	Ha	%
Water body	202,74	0,34	276,23	0,46	191,53	0,32
Forest	39.755,88	66,18	39.126,99	65,14	38.206,84	63,60
Mixed garden	2.466,39	4,11	4.356,84	7,25	8.638,15	14,38
Bare land	3.838,33	6,39	6.392,78	10,64	4.018,96	6,69
Mangrove	649,42	1,08	638,76	1,06	640,40	1,07
Rubber plantation	4.063,29	6,76	2.895,15	4,82	2.144,46	3,57
Palm oil estate	1.134,47	1,89	622,28	1,04	636,89	1,06
Settlement	1.103,86	1,84	1.506,74	2,51	2.453,09	4,08
Paddy field	98,08	0,16	298,90	0,50	202,27	0,34
Shrub	2.187,79	3,64	3.955,50	6,58	2.937,61	4,89
Cloud covered	4.569,94	7,61	0,00	0,00	0,00	0,00
Total	60.070,19	100,00	60.070,19	100,00	60.070,19	100,00

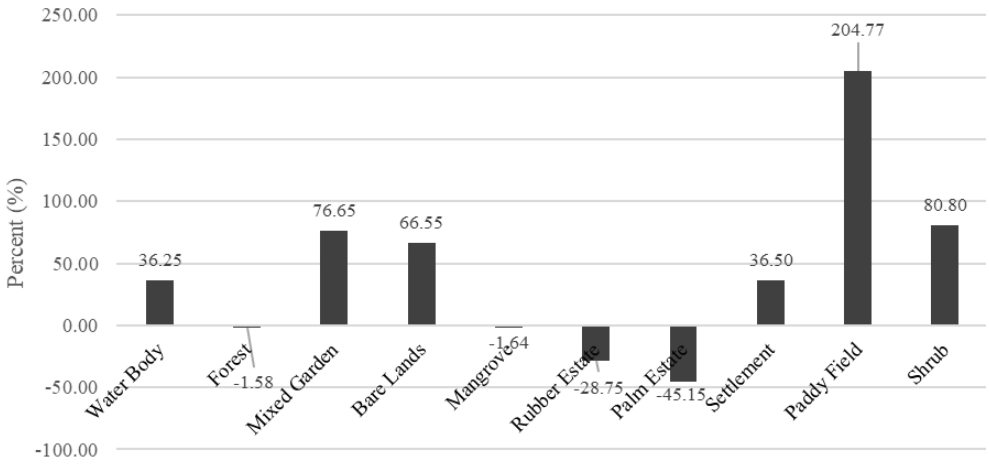

Figure 2. Graphics distribution in land cover change FMU XXV, 2001-2010

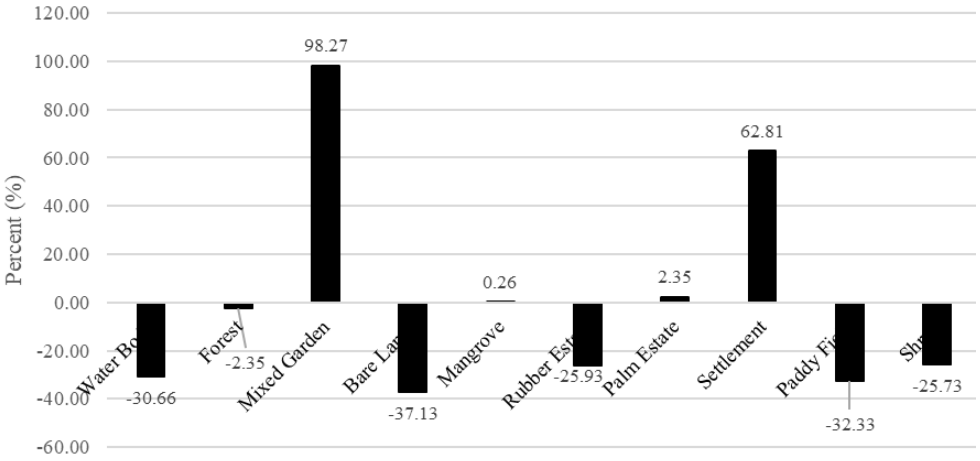

Figure 3. Graphics distribution in land cover change FMU XXV, 2010-2020

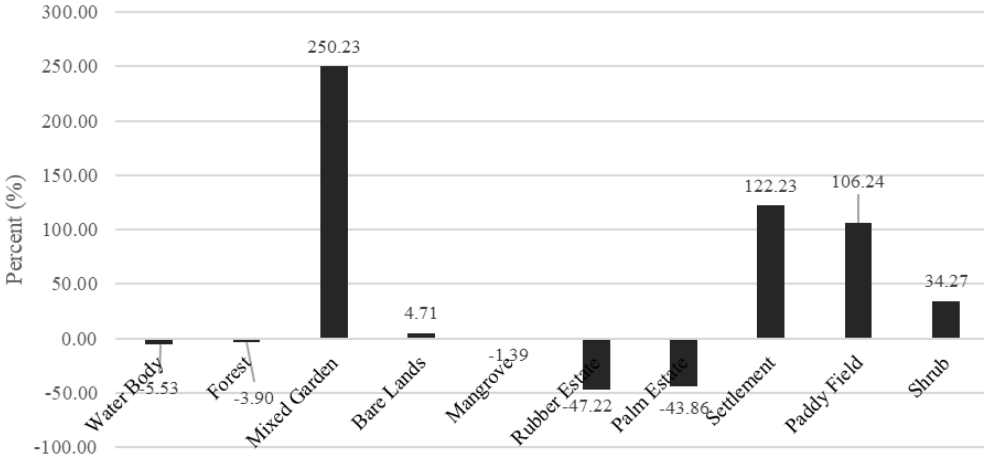

Figure 4. Graphics of land cover change in FMU Unit XXV North Sumatra, 2001-2020

Figure 3 shows that during the 2010-2020 period, the largest percentage increase in area in PFMU XXV was in mixed gardens of 98.27%. The cause of the increase in the area of mixed gardens in PFMU XXV is due to the shift in land use by the community to heterogeneous plants. There are various species that grow naturally and are also planted by the community. The species planted are the tree species that have high economic value including *Coffea arabica* L., *Durio zibethinus* Murray, *Archidendron pauciflorum* (Benth.) I.C.Nielsen and several other types of non-timber forest product (NTFP) plants. This follows Kogoya et al. (2016), which states that annual crops, and forestry are more suitable for cultivation by the community with agroforestry principles because these three species of crops can benefit farmers.

Mixed gardens experienced the most significant area increase in Production FMU (PFMU) XXV, growing by 98.27% between 2010 and 2020. The increase in the area of mixed gardens in PFMU XXV was due to the shift in land use by the community to heterogeneous plants. Different species grew naturally and were planted within the community. Planted tree species, including *C. arabica, D. zibethinus, A. pauciflorum*, and other non-timber forest products (NTFP), had high economic value. It followed the work of Achmad et al. (2022) and Samsuri et al. (2019), which suggested that annual crops and forestry are more suitable for community cultivation based on agroforestry principles.

The largest percentage of land cover decline occurred for bare land, which was 37.13% of the original area. Field observations showed that bare land cover occurred because of factors resulting from land clearing. Land-clearing was performed to convert the functions into other business areas. According to Sugianto (2022), conversion and cover decline occurred with the expansion of the area into settlements and agricultural land. The largest and smallest percentage of land cover class change were recorded in the oil palm plantation into bare land (57.9%) and mangrove class into water bodies (1.6%), respectively. Figure 4 shows data on the percentage of land cover change in PFMU Unit XXV North Sumatra between 2001 and 2020.

The largest percentage increase and decrease in the area of FMU Unit XXV North Sumatra were in mixed (250.23%) and rubber (47.22%) plantations from 2001 to 2020, respectively. Moktan et al. (2016) stated that the community readily converted natural forest, prioritising increased income. For example, converting forest to palm oil obtained €27 per individual daily, significantly more than the €13 from rubber plantations. Therefore, 47.1% of land cover class switches in oil palm farms occurred on bare land. This

barren land was slated for replanting due to the age of the palm trees.

The lowest change was reported in the mangrove land cover class for oil palm plantations, with a percentage of 1.2%. Population pressure due to high economic needs increased the demand for mangrove conversion. According to Ferreira et al. (2022), most mangrove areas were degraded, with some areas showing particularly poor conditions. The relatively large land cover change included the transition from oil palm to open land as well as mixed plantations. Meanwhile, the relatively small change comprised forest and mangrove being converted to settlements and oil palm plantations. Given the conditions, the shift from forest to other land uses was relatively small. Land cover of mixed gardens is expanding due to changes in individual behaviour, such as planting woody plants.

Forest cover change analysis

A deeper analysis of forest-nonforest change is presented in Table 2. Between 2001 and 2010, a total of 9,898.08 ha of forest was converted to non-forest areas. From 2010 to 2020, this conversion continued at a rate of 6,129.49 ha, though a regrowth or reforestation process also converted 5,221.51 ha of non-forest back to forest. The net change from 2001 to 2020 was a forest loss of 10,208.36 ha.

The area and percentage of forest cover for FMU XXV in 2010 and 2020 were presented through satellite image classification. In 2001, FMU XXV had a forest and non-forest cover of 44,975.25 ha (74.87%) and 15,094 ha (25.13%), respectively. The forest cover area decreased to 39,753.02 ha (66.18%) and 38,847.24 ha (64.67%). In FMU XXV, the area experienced both an increase and a decrease of 7% between 2001 and 2020. The largest change from forest cover to non-forest occurred between 2001 and 2010. Figure 5 shows the maps of land cover change for FMU XXV from 2001 to 2010, 2010 to 2020, and 2001 to 2020. Table 2 reports forest cover fluctuations from 2001 to 2020, with a slight increase in 2020. While a small area of non-forest land was converted back to forest between 2010 and 2020 (5,221 ha), the net change from 2001 to 2020 remained a significant forest loss of 6,109 ha.

Ethnoecological practices in local communities

In-depth interviews and surveys revealed the persistence of various ethnoecological practices among local communities surrounding FMU XXV. These practices were categorised into six main elements: local indigenous knowledge, utilisation of medicinal plants, wood, hunting wild animals, non-timber forest products, and traditional events. The physical and emotional closeness of humans to the natural resources created an interconnected system of interactions, leading to a mutual exchange of benefits. In addition, local indigenous knowledge provided an in-depth understanding (Adade Williams et al. 2020). This interactive process was identified within the FMU community of XXV North Sumatra, based on interviews that explored topics such as *Dando,* the pit of prohibition, medical plant usage, wood utilisation, firewood, and construction wood. In the Toba Batak tribe language, *Dando* refers to a hereditary rule and punishment system imposed on individuals proven to have stolen garden products from others. *Lubuk Larangan* (prohibition lake) is an area along the river that is mutually considered a forbidden location for fish consumption. The forbidden pit in Tukka Subdistrict was located in the middle of a protected forest area.

Table 2. Forest cover change of FMU XXV, North Sumatra

Land cover type	2001-2010		2010-2020		2001-2020	
	ha	%	ha	%	ha	%
Forest to forest	35,017.54	77.86	33,569.69	84.45	34,689.01	77.13
Forest to Non-forest	9,898.08	22.01	6,129.49	15.42	10,208.36	22.70
Non-forest to forest	4,690.05	31.10	5,221.51	25.72	4,099.37	27.18
Non-forest to non-forest	10,352.02	68.64	14,991.38	73.83	10,917.55	72.39

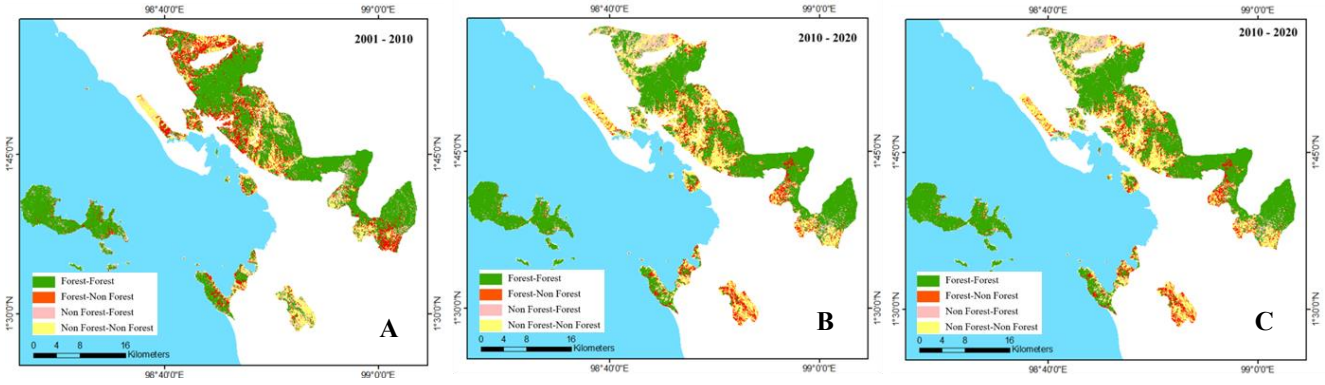

Figure 5. Forest cover change: A. The period of 2001-2010, B. The period of 2010-2020, C. The period of 2001-2020 in FMU XXV North Sumatra

Harvesting medicinal plants

Communities identified over 33 plant species used for traditional medicine. The medicinal plant species found in FMU XXV were used to treat 18 types of diseases, including stomach pain, cough, malaria, shortness of breath, stomach aches, toothache, colds, headaches, fever, wounds, ulcers, high blood pressure, rheumatism, canker sores, diabetes, appendicitis, and stomach**.** For example, bajakah (*Spatholobus littoralis* Hassk.) is used for wound healing, and sarindan (*Macrosolen flammeus* Danser) is used for the same purpose. Additionally, forests benefit humans (Fahmi et al. 2014) by providing the following essential natural resources.

The application of medicinal plants was categorised under ethnoecology due to the role as a fundamental strategy for human adaptation to the environment (Purwanto 2020). This adaptation method was passed down through generations, becoming a valuable pearl of wisdom within the FMU XXV community. According to the interview, 33 plant species were used for medical treatment. The most frequently used plant parts were the leaves, roots, rhizomes, and nests of the two fruit species. This was consistent with the assertion of Elfrida et al. (2021), where leaves were the easiest to collect without dependence on season. The gathering procedure was relatively straightforward compared with other organs (Ismail et al. 2020; Ramli et al. 2021; Djafar 2023).

Non-timber forest products

Harvesting of NTFPs remains common, with products like rattan (*Calamus* sp.), bamboo, and wild honey being collected for both subsistence and sale. NTFP commodities of the community include arenga water, latex, fruit, and animal hunting. Arenga water (nira) was derived from the male flower of the palm tree and served as the product of metabolism. Similarly, the FMU XXV community used sap from *Arenga pinnata* (Wurmb) Merr. tree. Tapping palm sap was considered by the local community as *Maragat.* Palm sap produced by *Paragat* was processed into a special drink, namely palm wine. Rubber tree sap (*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.) was used by the community, and the individuals were known as latex harvesters. Latex was harvested in the morning since non-timber forest products were used by the community as fruit. The utilization of NTFPs in the form of fruits from *D. zibethinus, A. pauciflorum, Lansium domesticum* Corrêa*, Garcinia mangostana* L.*., Parkia speciosa* Hassk.*,* and *Nephelium lappaceum* L. was the primary commodity cultivated. In addition to biological forest products, the community also used non-timber forest products derived from animals. The animal product produced was forest honey obtained from the hive of the honeybee (*Apis dorsata* Fabricius, 1793).

Forest-dependent communities in FMU XXV relied on a variety of non-timber products for food, trade, and cultural practices. Human knowledge of the utilization of the environment was also observed in the field of ethnoecology. Prasetyo et al. (2018) suggested that ethnoecology examines the coexistence of traditional societies with natural and social environments (Ilhami et al. 2021; Supyan 2021). The utilization of non-timber forest products (NTFPs) was analyzed using an ethnoecological method.

Traditional hunting practice

Hunting was quite diminished, but limited traditional hunting practices persist, focusing on wild boar and small mammals, often using traditional tools. Interviews with the community indicated that motivations for hunting included pest eradication, commercial sale, and personal consumption. The types of animals hunted by the community were wild boar (*Sus scrofa* Linnaeus, 1758), *Macaca fascicularis* (Raffles, 1821), *Tragulus kanchil* (Raffles, 1821), *Paradoxurus hermaphroditus* (Pallas, 1777), and *Serpentes* sp.

Hunting is an important activity for meeting the needs of life and a form of human adaptation to natural resources. This form of adaptation follows the ethnoecological method, which is the science of ecology and human adaptation (Alves 2018; Mekonen et al. 2020; Minin et al. 2021).

Firewood and construction materials

The use of fuelwood for cooking and specific timber species for building traditional houses (uma) continues, though respondents noted an increased reliance on alternative materials. Timber forest products were a fundamental necessity for individuals living in forested areas. The community used the wood for various purposes, such as construction, fuel, and handicrafts. Firewood was widely recognized as an essential fuel source used for cooking. The results showed that the community in FMU XXV used seven types of wood as firewood, including *D. zibethinus*, *S. littoralis*, *Schima wallichii* (DC.) Korth., *H. brasiliensis*, and *Samanea saman* (Jacq.) Merr. The community in FMU XXV also adopted wood for construction, a practice deeply rooted in cultural heritage. The types of wood used for house construction were *D. zibethinus*, *Alstonia pneumatophora* Backer ex Den Berger, *Dryobalanops aromatica* C.F.Gaertn.*, Phoebe hunanensis* Hand.-Mazz., and *Shorea sp*.

Cultural and ritualistic uses

Respondents demonstrated detailed knowledge of species phenology, animal behavior, and forest navigation. Certain plant and animal species hold cultural significance. Specific leaves and plants believed to carry spiritual meaning the *Maragat* ceremony. Local tribes in FMU XXV traditionally carried out firewood harvesting, poaching, and the collection of non-timber forest products. Most individuals in the FMU XXV area belonged to the Toba Batak and Nias tribes. This was reflected in the various traditional cultures developed and passed down from generation to generation. The events held in the community included *tonggo raja, mangamoti, parsahutan, maena, falewa, manabur same, mardege*, and traditional deliberating.

Tonggo raja is a traditional Batak Toba ceremony conducted to form a customary committee and discuss specific event preparation. *Mangamoti* is a ceremony performed in the form of thanks to the creator, and is carried out by eating together from the first harvest. Furthermore, *parsahutaon* is a traditional activity conducted by the community during major holidays, such as Eid al-Fitr and Christmas. *Maena* is a traditional dance performed as part of the Nias ceremony to welcome the harvest. *Falewa* is a traditional wedding ceremony for the Nias tribe. Hunting activities were carried out during the first

generation's *Falewa* event to obtain food and offerings. *Manabur* is a traditional community event at FMU XXV North Sumatra, which comprises planting rice seeds. *Mardege* is a stage in the rice harvesting process performed by stepping on grains with bare feet. Traditional deliberation is the customary mechanism for resolving conflicts and disputes in a community. The traditional meeting of the FMU XXV community is held in the village hall or the house of the head of the traditional leader.

Correlation between land cover change and ethnoecological practices

Correlation analysis was carried out to determine the significance of the relationship between independent variables (land cover change) and dependent variables (community ethnology). The correlation analysis used is the correlation of the contingency coefficient, which measures the relationship between land cover change and community ethnoecology. Contingency coefficient correlation analysis is a statistical measurement on a nominal scale. The statistical correlation between the observed land cover change (as an independent variable) and the six ethnological elements (as a dependent variable) was tested using the Chi-square test and the Contingency Coefficient. The results are presented in Tables 3 and 4.

Table 3 shows that for all six elements, the calculated chi-squared value is lower than the critical table value ($p > 0.05$). The Phi coefficient (φ) value is close to 0. Therefore, we fail to reject the null hypothesis (H_0). There is no statistically significant correlation between land cover change and the persistence of ethnoecological practices in the studied communities. Table 4 shows the correlation between ethnoecological forms in communities prioritising value management and land cover change. The relationship between the volume of forest use was reported as determined by the prevailing value system and land cover change. The results showed that the variables did not correlate significantly with land cover change. A potential mismatch existed between the evolving land-use configurations and the traditional ecological knowledge, as well as the prevailing intensity of flora and fauna resource utilisation in the adjacent forest of the community.

Discussion

Drivers and implications of land cover change

Positive change in land use, such as non-forested areas transitioning into forest, has been reported as a need for sustainable management. The forest cover change in North Sumatra suggests the need for sustainable land-use practices due to human activities and industrialisation. The largest area faced threats of conversion and degradation, with crop plantations dominating the planning process. The forest area in North Sumatra faced threats of conversion and degradation due to human activities. The interest in land allocation influences planning, favouring crop plantations over maintaining forests (Saputra and Lee 2019).

The largest percentage increase and decrease in the area of FMU Unit XXV North Sumatra were in mixed (250.23%) and rubber (47.22%) plantations from 2001 to 2020, respectively. Moktan et al. (2016) stated that the community readily converted natural forest, prioritizing increased income. For example, converting forest to palm oil obtained €27 per individual daily, significantly more than the €13 from rubber plantations. Therefore, 47.1% of land cover class switches in oil palm farms occurred on bare land. This barren land was slated for replanting due to the age of the palm trees.

The lowest change was reported in the mangrove land cover class for oil palm plantations, with a percentage of 1.2%. Population pressure due to high economic needs increased the demand for mangrove conversion. According to Ferreira et al. (2022), most mangrove areas were degraded, with some areas showing particularly poor conditions. The relatively large land cover change included the transition from oil palm to open land as well as mixed plantations. Meanwhile, the relatively small change comprised forest and mangrove being converted to settlements and oil palm plantations. Given the conditions, the shift from forest to other land uses was relatively small. Land cover of mixed gardens is expanding due to changes in individual behaviour, such as planting woody plants.

Table 3. Chi-square analysis for land cover change and ethnoecological change

	Ethno-ecological change	X^2 cal	df	X^2 table	Correlation
Land cover change	Local indigenous knowledge	0.907	1	2.706	No correlation
	Edible plant cultivation	0.000	1	2.706	No correlation
	Wood cultivation	0.907	1	2.706	No correlation
	Wildlife hunting	0.003	1	2.706	No correlation
	NFTP cultivation	1.786	1	2.706	No correlation
	Ethnicity event	0.000	1	2.706	No correlation

Table 4. Chi-square analysis of land cover change and outcome of ethnoecological change

	Ethno-ecological change	X^2 cal	df	X^2 table	Correlation
Land cover change	Local indigenous knowledge	0.643	1	2.706	No correlation
	Edible plant cultivation	0.374	1	2.706	No correlation
	Wood volume	1.250	2	3.605	No correlation
	Wildlife hunting volume	3.085	2	3.605	No correlation
	NTFP volume	1.255	2	3.605	No correlation
	A cycle of ethnic events	4.926	2	3.605	No correlation

Furthermore, deforestation rates in Indonesia have increased, with forest fires, poor management practices, and the demand for products contributing to damage, particularly in Sumatra. In this context, forest coverage must be periodically monitored to detect change and enhance resilience (Nurda et al. 2020). The oil palm plantation land cover category was reclassified in North Sumatra, showing land use change (Kevin et al. 2015). The modelling of change in Sumatra indicated a decline in forest cover, particularly peat swamp, until 2040, stating the need for sustainable management practices (Kevin et al. 2015).

The observed net loss of forest cover in FMU XXV is consistent with regional trends across Sumatra (Margono et al. 2014; Abood et al. 2015). Research on land cover change has been conducted by Samsuri et al. (2014); Firdaus et al. (2014); Basyuni et al. (2018), who reported forest degradation and land cover change in the North Sumatra area, specifically in the Tapanuli and Batang Toru Ecosystem (BTE). However, this research only identifies land cover change and driving factors, without analysing the ethnoecology factors. Depending on the environment and culture, the relationship between humans and land affects community characteristics. Our findings align with the broader narrative of tropical forest conversion driven by a complex interplay of factors. The transition of forest to plantation and agriculture (Table 2) can be attributed to the expansion of commercial agriculture, coupled with population growth and its attendant need for livelihood opportunities and food security (Dislich et al. 2017). This transformation poses a direct threat to the biodiversity values of the FMU, particularly its role as a habitat for critically endangered species like the Tapanuli orangutan (Haidir et al. 2013; Nater et al. 2017).

FMU XXV Management Area experienced a change in forest cover according to the local wisdom practices. Correlation testing between land cover change and shift in local wisdom practice was weak. The analysis did not report a significant relationship between land cover change and the community's use of non-timber forest products. The dominant non-timber forest product of the community was rubber tree sap (*H. brasiliensis*). Respondents stated that the decline in rubber sap was caused by the rainy season, low prices, and age. Rainfall strongly influenced the production of rubber latex crops. According to Habibulloh et al. (2023), the production volume and productivity of rubber plants did not increase. A decrease was reported, and the constant amount of production was influenced by rainfall.

The null correlation: A nuanced perspective

The results showed that land cover change had no significant correlation or relationship with a shift in traditional community activities. The decreasing intergenerational transmission of customary knowledge contributed to a decline in traditional event activities. Morris et al. (2015) stated that reduced understanding and learning from elder traditional leaders by the younger generation led to an indifference, impeding the regeneration of prevailing societal customs.

The lack of a statistically significant correlation is a fascinating and non-obvious result. It challenges a simplistic assumption that land cover change automatically erodes cultural practices (Benz et al. 2000). In the research, land cover change was only detected using medium-resolution satellite imagery, which has limited spatial resolution. The study's macro-scale land cover analysis may not capture the micro-habitat level where ethnoecological practices (e.g., harvesting specific plants) actually occur (Sayre et al. 2013). Practices may persist in remnant forest patches, mixed gardens that are not differentiated in a broader classification. In addition, the community has the adaptability to withstand changes that occur, ensuring that changes in ethnoecology do not have a direct effect on changes and vice versa. Communities are not passive observers but active adapters. The findings suggest they have adapted their practices to a changing landscape, for example, by cultivating previously wild-harvested species or shifting the geographic focus of their activities.

The ability of the community and traditional fanaticism is suspected to fortify their culture. Ethnoecological knowledge can be retained culturally through stories and rituals even as its practical application declines. This cultural inertia can decouple knowledge persistence from immediate environmental conditions. So, this null result is significant as it highlights that cultural resilience cannot be predicted solely from remote sensing data. It underscores the need for on-the-ground, socio-ecological research to understand the complex mechanisms at play.

Changes in local indigenous knowledge were due to technological developments and modernisation. Therefore, the mindsets of individuals changed, and traditional customs were abandoned. According to Maskur and Supriatna (2020), the community awareness factor ignored tradition but was more concerned with self-interest, as supported by evidence about local wisdom to strengthen existing social ties. The analysis reported no significant relationship between land cover change and shifts in community medicinal plant use. Therefore, plants for traditional remedies were primarily cultivated by residents in yards, gardens, or found growing wild nearby, ensuring easy access for medicinal purposes (Armawi and Limbongan 2022). This was consistent with Adade Williams et al. (2023), where the tendency to plant medicinal plants in the yards was driven by the experienced benefits (Erawan et al. 2018; Rizki et al. 2019). There was no significant correlation or relationship between land cover change and the community's use of wood (Table 3). The decline in the use of timber for firewood or building construction materials was caused by a shift in attitudes and behaviours toward the use of conventional fuels. Land cover change did not significantly correlate with variations in the community's wildlife hunting intensity. This was because most individuals hunt when pests damage the community gardens. The exact hunting intensity in a certain period could not be ascertained.

Resilience and erosion of ethnoecological knowledge

The persistence of diverse ethnoecological practices amidst significant landscape alteration is a notable finding. This resilience suggests a deep-seated cultural value attached to traditional knowledge systems, which can act as a buffer against rapid environmental change (Gómez-Baggethun et al. 2013). Practices like the use of mixed gardens for

medicinal plants represent a strategic adaptation, allowing communities to maintain knowledge even as access to primary forest diminishes (Reyes-García et al. 2014).

However, the interviews also revealed signs of erosion. The reported shift towards conventional medicine and fuels indicates a gradual weakening of this knowledge base, particularly among younger generations, a trend documented elsewhere in Indonesia (Moeliono et al. 2014; Sterling et al. 2017). This creates a precarious situation where knowledge systems are preserved, but their practical application and transmission are increasingly vulnerable.

Implications for Forest Management Unit (FMU) policy

For FMU XXV managers, these findings offer important and actionable insights. The persistence of ethnological practices is an important asset for community-based conservation (Danielsen et al. 2005). Management strategies should actively integrate Traditional Ecological Knowledge (TEK) into forest planning (Berkes 2009; Sutherland 2014). This could include several strategic policies by FMUs XXV. Unit management should involve local communities as partners in biodiversity monitoring, leveraging their species identification skills. Ethnoecology can assist FMU in managing forest ecosystem biodiversity (Golar et al. 2021; Tynsong 2021). Integrating different knowledge systems (scientific and traditional) will support the achievement of effective environmental management (de Araujo Lima Constantino et al. 2012; Hoagland RJ 2016).

As a form of FMU's presence in the community, supporting the cultivation of medicinal and NTFP species is important in the agroforestry system to reduce pressure on primary forests. Maintaining cultural practices must be a priority in planting activities (Shackleton 2015). To nurture and foster community spirit in preserving forest landscapes, FMUs must develop educational programs that document and facilitate the intergenerational transmission of this knowledge (Carson et al. 2018; McCarter 2018). FMUs should also document the process of knowledge erosion and highlight the critical need for educational programs to serve as a reminder and revitalise this knowledge. It is undeniable that at this time there are threats to intergenerational knowledge transmission. This is important and requires proactive programs to maintain it.

In addition, the policy must recognise the intrinsic link between cultural preservation and biodiversity conservation (Sterling et al. 2017). Especially if the characteristics of the communities that depend on the FMUs landscape forest are more varied, therefore the biological and cultural diversity are inextricably linked and must be conserved together. Hence, a successful FMU model must support the ecological integrity of forests and the socio-cultural integrity of the communities that depend on them.

This research provides a nuanced understanding of the socio-ecological dynamics within FMU XXV in North Sumatra, quantifying a significant net loss of forest cover over two decades (2001-2020) due to conversion to agriculture and plantations, while also documenting the persistent diversity of land covers, including forest, mixed gardens, and plantations. The most striking finding is the lack of a statistically significant correlation between these land cover changes and the preservation of traditional ethnoecological knowledge, which challenges the assumption that deforestation inevitably results in cultural degradation. Instead, communities demonstrated tremendous adaptation capacity by sustaining traditions such as mixed gardens, remaining forest patches, and farming with once-wild species. As a consequence, the management paradigm for FMU XXV has to evolve beyond a strictly biological focus; the preservation of ethnoecological knowledge is a critical asset for future conservation. The study suggests that FMU policies actively integrate this living cultural heritage into community-based management activities, ensuring its long-term sustainability. Future research should conduct an in-depth analysis to determine the conditions under which technological advances and connectivity may hinder ethnoecological activity.

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