

Indigenous knowledge and forest-based livelihoods in the context of climate change: Evidence from the Dao community in Lai Chau province, Vietnam

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Abstract

Climate change poses serious challenges to mountainous socio-ecological systems, where community livelihoods depend heavily on forest resources and natural environmental conditions. In this context, indigenous knowledge is considered a crucial resource for adaptation; however, its role as a socio-economic governance system remains unclear. This study analyzes the role of indigenous knowledge in shaping forest-based livelihoods and climate change adaptation among the Dao ethnic community in Lai Chau province, Northern Vietnam, using a mixed-use approach combining qualitative data from in-depth interviews and focus groups with quantitative data from surveys of 200 households. The results show that indigenous knowledge functions as an informal governance system through customary practices and community institutions, contributing to regulating forest resource use and supporting livelihood diversification. However, the effectiveness of this system is declining under the impact of climate change and socio-economic transformations, leading to the emergence of an “adaptation gap” between risk perception and actual response capacity. The study highlights the dynamic nature of indigenous knowledge and suggests the need to integrate institutional and policy resources to enhance adaptability in the context of current change.

Keywords: Indigenous knowledge; Forest-based livelihoods; Climate change; Adaptation; Adaptation gap; Resource governance; Dao people; Lai Chau province

1. Introduction

Climate change is increasingly recognized as one of the most serious challenges to socio-ecological systems, especially in rural and mountainous areas, where community livelihoods depend heavily on natural resources and environmental cycles. Globally, numerous studies have shown that indigenous communities are both vulnerable and crucial in adapting to climate change due to their knowledge systems accumulated over generations (IPCC, 2022; Berkes, 2012). Unlike the approach that views indigenous knowledge as merely a collection of disparate experiences, contemporary research emphasizes that it is a complex system encompassing ecological understanding, cultural norms, and social institutions that shape the relationship between humans and the environment (Agrawal, 1995; Berkes, 2012). In many cases, these systems function as informal governance mechanisms, regulating access to and use of shared resources in the context of limited state management (Ostrom, 1990).

From the perspective of shared resource theory, indigenous knowledge is linked to governance structures capable of maintaining the sustainability of ecosystems and livelihoods. Local communities often establish rules for resource use based on social consensus, combined with monitoring and enforcement mechanisms integrated into daily life (Ostrom, 1990). These mechanisms not only help regulate exploitation behavior but also contribute to benefit allocation and conflict mitigation within the community. However, these systems are not immutable, but are affected by factors such as social stratification, power relations, and broader socio-economic changes (Cleaver, 2002). Therefore, the

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effectiveness of indigenous knowledge in resource management and climate change adaptation depends on the adaptability of local institutions in specific contexts.

In relation to livelihoods, the role of indigenous knowledge is particularly prominent in forest-based livelihood systems, which are prevalent in tropical and mountainous regions. Many studies have shown that forests not only provide material products but also act as a “livelihood safety net,” helping households mitigate risks from environmental and economic shocks (Angelsen et al., 2014). In mountainous areas, where agricultural production conditions are limited by terrain and climate, livelihoods are often organized in a diversified manner, combining shifting cultivation, non-timber forest product harvesting, and small-scale livestock farming (Fox et al., 2009). In this context, indigenous knowledge not only guides production practices but also plays a crucial role in regulating the timing, space, and intensity of resource use.

However, forest-based livelihood systems are facing numerous pressures in the context of globalization and climate change. The increase in extreme weather events, along with changes in rainfall and temperature patterns, is increasing the uncertainty of the natural environment (IPCC, 2022). Simultaneously, market integration and state-led resource management policies have altered traditional land use and forest exploitation patterns, sometimes creating overlaps or conflicts with indigenous governance mechanisms (Dressler et al., 2010; Sikor, 2001). In this context, although local communities maintain many experience-based adaptation strategies, the effectiveness of these strategies is not unlimited.

Recent studies show that the adaptive capacity of communities depends not only on knowledge but is also influenced by access to resources, institutional flexibility, and broader socio-economic conditions (Adger, 2006; Smit & Wandel, 2006). From this perspective, the concept of an “adaptation gap” is used to describe the disparity between the adaptation needs and the actual adaptive capacity of socio-ecological systems (Folke et al., 2010). This gap can arise when traditional knowledge and practice systems, although still valuable, are no longer sufficient to cope with the scale and speed of current environmental change.

In the context of Vietnam, the northern mountainous regions are typical examples where the relationships between indigenous knowledge, forest-based livelihoods, and adaptation to climate change are clearly demonstrated. Numerous studies have shown that ethnic minority communities in this region are significantly dependent on forest resources, not only as a source of livelihood but also as a support system for adaptation to environmental shocks (Sikor & Nguyen, 2007; McElwee, 2012). Among them, the Dao people are noted as a group with a rich system of indigenous knowledge, particularly related to forest management, the use of non-timber forest products, and folk medicine. Studies on the Dao people's botanical knowledge and medicinal plant use reveal a high level of biodiversity linked to local knowledge, playing a crucial role in maintaining livelihoods and community health.

2. Research area and methods

2.1. Research area

The study was conducted in Lai Chau province, a mountainous province in the Northwest region of Vietnam. According to the General Statistics Office, Lai Chau has an area of approximately 9,068 km² and a population of about 480,000 people, with a low population density and uneven distribution due to complex topography (GSO, 2022). The province's topography is mainly high mountains and heavily dissected, with most of the area located at an altitude of over 500 m above sea level. The climate is tropical monsoon in the high mountains, characterized by a rainy season lasting from May to October, with heavy rainfall and a high risk of extreme weather events such as flash floods and landslides (MONRE, 2020).

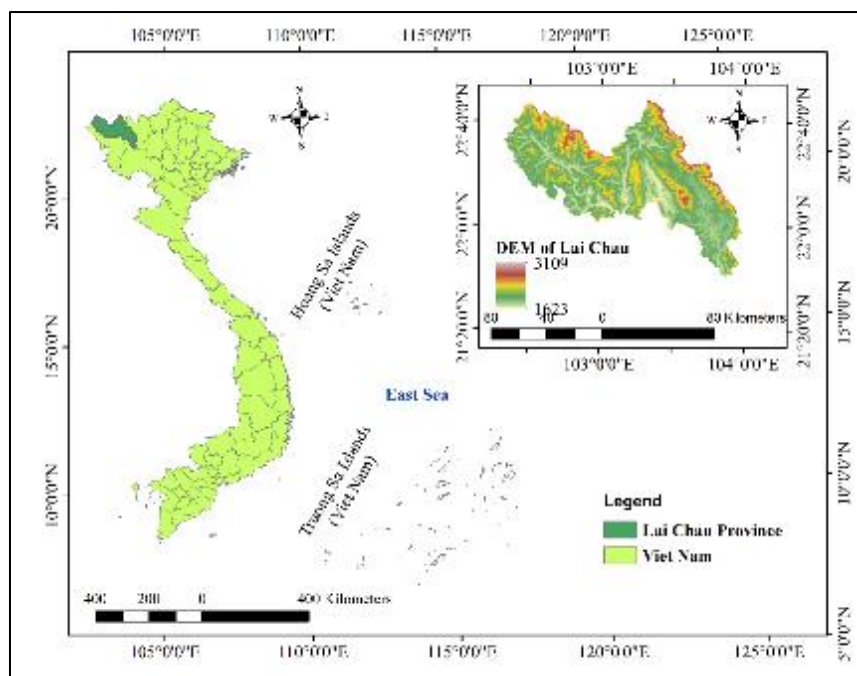


Figure 1 Local of Lai Chau province in Vietnam

Lai Chau is home to many ethnic minority groups, with the Dao people accounting for approximately 12–13% of the province's total population (GSO, 2019). Dao communities are typically located in highland areas where agricultural production is limited. Their livelihoods are primarily based on slash-and-burn agriculture, combined with the exploitation of non-timber forest products and small-scale livestock farming. In this context, forests play a crucial role as a source of livelihood and are a central element in local socio-economic systems.

Besides livelihood characteristics, the study area is also notable for the existence of indigenous knowledge systems linked to resource management and environmental adaptation. However, in recent years, Lai Chau has been identified as one of the provinces most severely affected by climate change in the northern mountainous region, with an increasing trend of extreme weather events and fluctuations in rainfall patterns (MONRE, 2020). These changes are posing significant challenges to the traditional livelihood systems of ethnic minority communities.

2.2. Research Design and Data Collection

The study was conducted using a mixed-methods approach, combining qualitative and quantitative methods to analyze the role of indigenous knowledge in livelihoods and adaptation to climate change (Creswell, 2014). This approach allows for in-depth exploration of local knowledge systems while identifying common trends at the household level.

Primary qualitative data was collected through fieldwork conducted in selected Dao villages located in mountainous areas with high forest cover and limited accessibility. Data collection included semi-structured interviews with household representatives, village chiefs, and key informants with extensive knowledge of local resource management practices. In total, approximately 25–30 in-depth interviews were conducted, focusing on topics such as forest use, customary governance, seasonal livelihood strategies, and changes in climate pattern perceptions. These interviews were supplemented by direct field observations, providing contextual insights into daily livelihood activities, spatial patterns of resource use, and the practical application of local indigenous knowledge. To support and validate the qualitative findings, a structured household survey was conducted with 200 households across the study area. The survey instrument was designed to gather household perceptions of forest dependence, the importance of water resources, climate change, and the effectiveness of traditional adaptation practices. Responses were measured using Likert scale items, allowing for the identification of general trends and differences among households. The survey was not intended to draw statistically representative conclusions on a broader scale; instead, it was used to provide an empirical basis for the main models observed during the qualitative field study.

In addition to primary data, secondary sources were also consulted to clarify the study area context and support the interpretation of empirical findings. These included provincial-level statistical reports, government documents on forest management and land use, and existing academic literature on indigenous knowledge, rural livelihoods, and

adaptation to climate change in Southeast Asia. Integrating these sources allowed the study to place local observations within a broader environmental and institutional dynamic context, thereby enhancing the analytical depth and external applicability of the findings.

2.3. Analytical Methodology

This study employs a predominantly qualitative mixed-methods design to examine the role of indigenous knowledge in shaping forest-based livelihoods and climate change adaptation. The analytical strategy is based on an interpretive framework, where qualitative insights form the core of the analysis, while quantitative data are used to support, validate, and refine the observed models. This approach is particularly suitable for studying indigenous knowledge systems, where meaning, practices, and institutional dynamics are deeply intertwined within the local socio-cultural context.

Qualitative data were analyzed using thematic analysis. Interview transcripts and field notes were organized and coded according to a set of initial categories derived from the conceptual framework, including resource governance, livelihood practices, and adaptation strategies. These categories were then refined through multiple data rereadings, allowing for the identification of emerging themes and relationships. The coding process combines deductive and inductive reasoning, ensuring that the analysis remains theoretically informed while also relying on empirical observations. The study places particular emphasis on identifying how indigenous knowledge is applied in practice, especially in relation to decision-making processes, resource use patterns, and responses to environmental change.

Quantitative data from household surveys are analyzed using descriptive statistical techniques to identify general trends in perceptions related to forest dependence, climate change, and adaptation. Instead of emphasizing statistical inference, the analysis focuses on central trends and distribution patterns as indicators of broader community-level dynamics. To increase clarity and consistency, survey results are aggregated into key indicators capturing overall trends in household responses.

The integration of qualitative and quantitative data was achieved through triangulation, whereby findings from different sources were systematically compared and interpreted in relation to one another. Similarities between interview-based insights and survey-based trends were considered to strengthen the robustness of the analysis, while differences were examined to uncover potential variations between households or tensions.

2.4. Analytical Framework

This study utilizes an integrated analytical framework to clarify the relationship between indigenous knowledge, governance systems, forest-based livelihoods, and adaptation to climate change. In this framework, indigenous knowledge is considered the foundation shaping the rules and practices of resource management; customary governance systems act as intermediaries regulating resource use; forest-based livelihoods reflect the results of these interactions; and adaptation to climate change is viewed as a dynamic process influenced by both environmental conditions and socio-economic context.

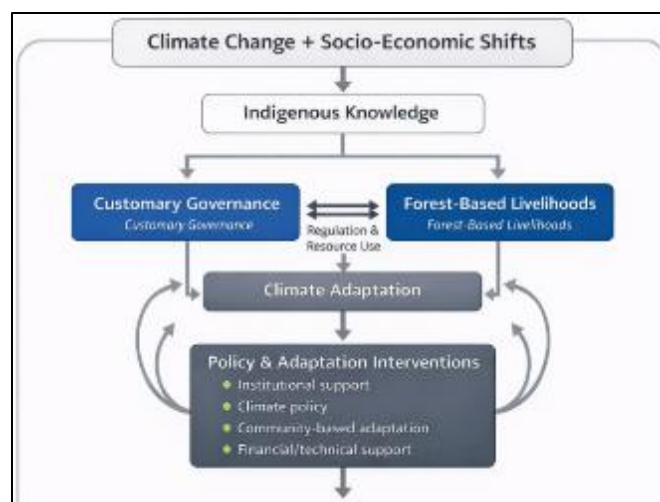


Figure 2 Conceptual Framework of Indigenous Knowledge, Forest-Based Livelihoods, and Climate Adaptation under Socio-Environmental Change

3. Results

3.1. Indigenous knowledge as a governance system in forest resource utilization

For the Dao community in Lai Chau, indigenous knowledge is clearly demonstrated through activities such as non-timber forest product exploitation, integrated agroforestry on sloping land, the use and conservation of medicinal plants, and community-based forest management institutions.

3.1.1. Sustainable exploitation of non-timber forest products

Lai Chau also possesses diverse biological resources with a large forest area and rich ecosystem, including many endemic plant, medicinal, and animal species of the northern mountainous region. These natural conditions not only provide a foundation for forestry development and forest-related livelihood models for ethnic minority communities but also have significant importance for biodiversity conservation and adaptation to climate change in mountainous areas.

Table 1 Forest Status of Lai Chau Province (2010 – 2024)

Forest Status	2010	2015	2020	2024
Total Forest Area (thousand ha)	383,6	416,4	462,4	488,4
Natural Forest (thousand ha)	358,3	404,0	441,9	459,4
Planted Forest (thousand ha)	25,3	12,4	20,5	29,0
Forest Cover Rate (%)	41,2	45,4	50,9	53,0

Source: <https://www.nso.gov.vn/> (Vietnam National Statistics Office)

The total forest area of Lai Chau province has shown a continuous upward trend over the years. In 2010, the forest area reached 383.6 thousand hectares; by 2024, it reached 488.4 thousand hectares. Thus, in the period from 2010 to 2024, the province's forest area increased by approximately 104.8 thousand hectares, demonstrating the positive results achieved in forest protection, restoration, and development in the locality. Natural forests account for a large proportion of the forest area and are trending upwards. This reflects the important role of forest protection policies, natural forest regeneration and restoration in recent years. The area of planted forests fluctuates but generally shows an upward trend. The province's forest cover rate has increased significantly over time. From 41.2% in 2010, forest cover increased to 45.4% in 2015, 50.9% in 2020, and is projected to reach 53.0% in 2024. This indicates that Lai Chau province's forest resources are gradually recovering and developing, making a significant contribution to environmental protection, biodiversity conservation, and creating a foundation for the development of forest-based livelihoods for local communities.

One of the clearest manifestations of the Dao people's indigenous knowledge is their deep understanding of the ecological characteristics and growth cycles of non-timber forest products. Products such as bamboo shoots, forest mushrooms, honey, wood ear mushrooms, herbs, and medicinal plants play an important role in the livelihoods of many households. However, the exploitation of these resources is often carried out according to traditional rules to avoid resource depletion.

The forest is rich in bamboo shoots, shiitake mushrooms, wood ear mushrooms, and wild vegetables (such as wild spinach and wild sweet potato leaves). Nowadays, ethnic minority communities harvest these products not only for their own family needs but also to sell at the market. Most forest products are harvested during the rainy season, as this is when trees grow and develop best and recover quickly. Harvesting non-timber forest products for food is relatively simple and easy.

- Bamboo shoots: Lai Chau is famous for its wide varieties of fresh, clean, and distinctive wild bamboo shoots, such as bamboo shoots from the Nua tree (bud/sprout), the Vau tree (bamboo sheath), the Sat tree, the Giang tree, and the Truc tree. These shoots are usually harvested in the spring, notable for their sweet, crunchy taste, and are processed into dried bamboo shoots, shredded bamboo shoots, or consumed fresh.

- Shiitake mushrooms: These mainly grow in the autumn and winter, often appearing on fallen tree trunks. This type of mushroom has a milky white color, small caps, and a fragrant aroma, hence its name, shiitake mushroom. To obtain a

large quantity of shiitake mushrooms, people often go into the forest to cut down several trees in November and May of the lunar calendar, mainly chestnut trees, to create a suitable environment for the mushrooms to grow and develop. Distinguishing between poisonous and non-poisonous mushrooms depends entirely on the experience of the mushroom picker. Locals say that mushrooms that haven't been touched by insects or small animals, usually have vibrant colors, and when cut, release a milky white substance, are poisonous. To preserve the mushrooms for a long time, people usually dry them, then hang them in a basket in the kitchen attic. When needed, they take them down, soak them in water to soften them, wash them clean, and cut off the stems before use.

- "Rau bò khai" (a type of vegetable): This vegetable is so named because it has a slightly pungent smell, especially after eating. After digestion, the urine will have a pungent odor. The plant resembles the chayote plant but is more slender, has more tendrils, and is a more delicate, light green color. The wild spinach plant usually grows in rocky mountainous areas, clinging to large trees for support. According to the Dao ethnic people, wild spinach is harvested in the spring and is believed to cool the liver and improve health.

- In addition, there are many other forest products that have been harvested by ethnic communities for generations to serve their lives, such as various vegetables (Centella asiatica, Amaranth, Portulaca oleracea, Erythrina variegata...), various tubers (Dioscorea opposita, Dioscorea spp....), various wild fruits (wild berries, mulberries, myrtle...), and various spices (star anise, cinnamon, turmeric, ginger...).

In practice, the Dao community applies the principle of selective harvesting, only collecting a portion of the yield and preserving the parent plants to ensure the natural regeneration of the plant population. For example, when harvesting bamboo shoots or medicinal plants, people typically only harvest plants that have reached a certain size, while leaving young plants or seedlings to maintain the resource for the next season. In addition, harvesting is regulated according to seasonal cycles, with communities avoiding harvesting during the growth or flowering and fruiting stages of many forest plant species. These rules form a resource management mechanism based on the ecosystem's recovery threshold, helping to maintain the long-term supply of non-timber forest products.

3.1.2. Conservation of Medicinal Plant Biodiversity Under Forest Canopy

The indigenous knowledge system of the Dao ethnic community in Lai Chau province plays a key role in the management and conservation of medicinal plant resources. Field studies show that the Dao people are very skilled at classifying medicinal plants, based on morphological, ecological, and therapeutic characteristics. This knowledge is not limited to identification but also encompasses sustainable harvesting techniques, complex processing procedures, and specific medicinal plant combination formulas.

In the study area, the model of cultivating medicinal plants under the forest canopy is maintained as an adaptive livelihood method. Integrating medicinal plant species into the natural forest ecosystem has created an effective in-situ conservation mechanism. This model establishes a symbiotic relationship: the community protects the forest to maintain a "living medicinal plant garden," while the forest cover provides an optimal microclimate for the growth of valuable medicinal plant species.

Currently, the Dao people in many communes are actively cultivating valuable medicinal plants under the forest canopy, such as Lai Chau ginseng, seven-leaf one-branch flower, golden orchid, artichoke, tea vine, and cardamom. These plants bring high economic value, helping people sustainably alleviate poverty. Ginseng: A key, endemic crop that is being preserved and strongly developed in communes such as Si Lo Lau, Khun Ha, and Ta Leng. Artichoke: Widely grown in the Sin Ho plateau, it is one of the main OCOP products of the locality. Tea vine, cardamom, and various medicinal leaves: Grown and harvested for medicinal purposes.

Among the medicinal plants grown under the forest canopy, ginseng is the most valuable. Ginseng increases in value the longer it is grown; therefore, cultivating and harvesting ginseng not only brings immediate economic benefits but also long-term value and great economic potential for the people. Lai Chau province has been implementing the project "Building a model for cultivating and propagating Lai Chau ginseng to preserve and develop this endemic product in the highland communes of Lai Chau province"... Based on this, the province has provided support to local people with seedlings of rare medicinal plants; supported conservation and perfecting the production and propagation process; supported the development of commercial medicinal plant cultivation, including consulting costs for building linkages, infrastructure serving linkages, costs for transferring and applying new scientific and technical knowledge; and supported agricultural cooperatives in participating in the linkage chain...

Besides cultivated medicinal plants, the Dao people also exploit medicinal plants available in the forest. The medicinal plants used by the Dao people in Lai Chau are mainly harvested from cliffs, mountain peaks, caves, and streams. Thanks to careful observation and a process of "trial and error," the Dao people have accumulated a lot of experience in identifying the uses of medicinal plants and the usable parts of them. Some plants are harvested for their leaves, some for their roots, some for their fruits, and some for their flowers, or even the entire plant is used, without discarding any part. The remedies are very diverse, ranging from treating stomach aches and diarrhea, bone and joint pain, and stopping bleeding, to treating skin diseases or for beauty purposes... Some remedies only require one type of herb, while others require a combination of many different types. Some medicinal herbs are simple and easy to find, commonly used in daily life for various purposes such as spices in food preparation (mugwort, turmeric, galangal, ginger...), blood-boosting drinks, and cooling drinks (licorice, *Artemisia capillaris*...). Many medicinal herbs are unknown to the local people; some are used according to their ethnic language, and most of these names indicate the characteristics, methods, or uses of the herb.

3.1.3. Community Forest Management Institutions and Cultural and Religious Values

Besides knowledge related to resource exploitation and utilization, the Dao people maintain many traditional institutions in community-based forest management. In many villages, certain forest areas are considered sacred or forbidden forests, closely associated with traditional religious values and rituals. These forests are usually strictly protected, with no or only permitted exploitation in special circumstances. This contributes to the formation of "core zones" for biodiversity conservation within the community's ecological space.

The Dao community also maintains community agreements (village regulations) related to forest protection and exploitation. The culture of worshipping and preserving the forest, and respecting nature, practiced by the Dao people and some other ethnic groups in Lai Chau province, is incorporated into the village regulations and strictly adhered to by the people, contributing to the creation of sustainable livelihoods for the people under the canopy of the old-growth forest. In many communes and villages, forest conservation has been incorporated into community regulations, with laws to handle violations. For example, the regulations of Ta Phin commune clearly state: "Forest conservation is the responsibility of all people in the commune and village. Logging and indiscriminate slash-and-burn farming are strictly prohibited. When it is necessary to use wood, there must be a plan with specific quantities and specific tasks, and notification must be given to the commune government and the forest protection agency. Permission must be obtained and a permit must be obtained".

3.2. Indigenous Knowledge in Climate Change Adaptation

The research results show that indigenous knowledge plays a central role in shaping the forest-based livelihood strategies of the Dao ethnic community, particularly through the mechanism of diversifying economic activities and adapting flexibly to environmental changes. Household survey data ($n = 200$) shows that the majority of households do not depend on a single source of income but maintain combined livelihood strategies. As presented in Table 2, approximately 37% of households follow a mixed livelihood model, 34% are primarily based on agriculture, and 29% have a high degree of dependence on forestry. This structure reflects the typical characteristics of highland livelihoods, in which indigenous knowledge is applied to allocate resources and mitigate risks in a changing environment.

The socio-economic characteristics of the surveyed households are summarized in Table 2, showing the predominance of mixed and forest-dependent livelihood systems, reflecting the strong integration between agricultural activities and forest resource use in the study area.

Table 2 Socio-economic characteristics of surveyed households ($n = 200$)

Variable	Type	Percentage (%)
Gender	Male	56
	Female	44
Age	<30	18
	30–50	57
	>50	25
Type of livelihood	Agriculture	34

	Forestry	29
	Mixed livelihood	37
Education level	Primary	46
	Secondary	38
	High school	16

Indigenous knowledge plays a crucial role in shaping how Dao communities respond to environmental change and climate-related risks, particularly in the context of forest-based livelihoods. Instead of relying on imported technologies or formal adaptation programs, households primarily rely on accumulated experiential knowledge to adjust their activities in a way that is context-appropriate and resource-sensitive. These adaptive responses are integrated into daily livelihood activities, reflecting the close links between ecological conditions, cultural practices, and local decision-making processes. Specific household adaptation livelihood models are summarized in Table 3, illustrating how indigenous knowledge is applied in integrating economic activities to respond to climate change. This demonstrates that indigenous knowledge not only plays a role in maintaining traditional practices but also supports livelihood restructuring in the context of change.

Table 3 Some climate change adaptation livelihood models of Dao households

Livelihood Model	Activity Components	Adaptation
Agriculture + Non-timber forest products	Shifting cultivation combined with harvesting bamboo shoots and medicinal herbs.	Reduce the risk of crop failure and supplement income during the lean season.
Agriculture + livestock	Crop farming combined with small-scale livestock raising	Utilizing agricultural by-products to diversify livelihood risks.
Forestry + Livestock	Forestry combined with grazing.	Utilize forest resources and reduce reliance on agriculture.
Mixed livelihoods	Combining agriculture, forestry, and non-agricultural labor.	Increased flexibility and better adaptation to climate change.

Most Dao villages in Lai Chau are located in mountainous areas with steep slopes, where soil and climate conditions are highly variable. With a predominantly mountainous terrain, steep slopes, and rich forest ecosystems, the livelihoods of the Dao people here are closely tied to land and forest resources. Through long-term settlement, the community has developed many production and livelihood models based on indigenous knowledge, demonstrating flexible adaptation to harsh natural conditions and climate changes. These livelihood models not only contribute to food security but also help maintain the stability of agricultural and forest ecosystems in the highlands.

Table 4 Some livelihood models adapted to climate change

No.	Location (commune)	Livelihood Model	Significance of Adaptation to Climate Change
1	Ta Leng (Tả Lềng) (~ 2000m)	Cardamom under the forest canopy	Cardamom plants are grown under the canopy of natural forests at high altitudes, utilizing the forest cover to create a suitable microclimate for the crop. This model helps maintain forest cover, limit soil erosion, protect upstream water sources, and create a stable income for the people, thereby reducing pressure on natural forest exploitation.
2	Sa De Phin (Sà Dề Phìn) (~ 1.700m)	Terraced rice fields	Terraced rice paddies help retain water and reduce soil erosion on sloping terrain. The terraced system also helps accumulate silt and maintain soil fertility, thereby reducing the impact of extreme weather events such as heavy rains or droughts.
3	Ta Phin (Tà Phìn)	Snow Shan tea	Shan Tuyet tea is grown under the forest canopy or in high mountainous areas with a cool climate. This model contributes to maintaining the

	(~ 1500 m)		forest ecosystem, increasing soil and water retention, and creating a high-value specialty agricultural product for the community.
4	Pa Ve Su (Pa Vê Sủ) (~ 900 – 1.500m)	Medicinal plants under the forest canopy	Medicinal plants such as cardamom, angelica, star anise, and ginseng are grown under the forest canopy, taking advantage of natural moisture and shade. This model helps conserve the forest, create stable livelihoods, and contribute to the protection of rare plant genetic resources.
5	Ma Quai (Ma Quai) (~ 1500 m)	Multicropping	On the same plot of land, people cultivate a combination of crops such as upland rice, corn, cassava, potatoes, and fruit trees. This crop diversification helps to mitigate the risks posed by climate change, while maintaining soil fertility and ensuring food security for households.
6	Ka Lang (Ka Lãng) (~ 1.300m)	Non-timber forest products	Products such as bamboo shoots, honey, mushrooms, and medicinal plants are harvested seasonally. This activity helps diversify livelihoods, reduce dependence on traditional agricultural production, and increase adaptability to climate change.

One of the typical livelihood models of the Dao people in Lai Chau is cardamom cultivation under the forest canopy, common in highland communes, notably Ta Leng commune. In this model, cardamom plants are grown under the canopy of natural forests at altitudes from 1,500 m to over 2,000 m, where the climate is cool and humid. This cultivation system utilizes the forest cover to create a suitable microclimate for the plants, while also limiting soil erosion and maintaining soil moisture during the dry season. Cardamom cultivation does not require extensive deforestation, thus contributing to maintaining forest cover and protecting upstream forest ecosystems. Besides its ecological value, cardamom is also a valuable cash crop, increasing income for many Dao households and reducing the pressure of exploiting forest resources in a destructive manner.

Besides their forest-based livelihoods, the Dao community in Lai Chau maintains a system of terraced rice fields on the mountain slopes to adapt to the steep terrain and heavy rainfall. The terraced fields are built along contour lines, helping to retain water and limit soil erosion. This is a characteristic form of land reclamation by mountain dwellers, demonstrating the community's deep understanding of natural laws. In the context of climate change and increasingly erratic rainfall, terraced rice fields play a crucial role in stabilizing rice production, minimizing the risk of landslides, and maintaining soil fertility. At the same time, the terraced rice fields create a distinctive agricultural landscape of the Northwest mountainous region, contributing to the development of ecotourism and community tourism.

Another prominent feature of the Dao people's livelihood in Lai Chau is the diversification of crops grown on their terraced fields. On the same area of land, they often combine various crops such as upland rice, corn, cassava, potatoes, beans, and fruit trees. Crop diversification helps to spread production risks, especially in increasingly volatile climate conditions. If one crop is affected by drought or pests, other crops can still ensure a yield, thereby minimizing the risk of crop failure. This diversified farming system also contributes to maintaining soil fertility, as each crop has different nutritional needs and can replenish organic matter in the soil through plant residues. Through traditional experience, the Dao people apply intercropping and crop rotation techniques to maintain soil fertility and limit soil degradation. For example, after a cycle of growing corn or upland rice, people can switch to growing legumes or forestry trees to improve soil nutrition. At the same time, planting species with deep root systems and wide canopies increases surface cover, thereby minimizing leaching and erosion on sloping terrain. Studies on mountain livelihoods also show that agroforestry models have the potential to enhance the stability of production systems and increase the resilience of communities to climate change.

The livelihood models of the Dao people in Lai Chau demonstrate a harmonious combination of indigenous knowledge and local ecological conditions in the process of organizing production territories. Models such as cardamom cultivation under forest canopy, terraced fields, crop diversification, and the development of forest medicinal plants not only help increase income for the community but also contribute to the protection of forest ecosystems and land.

3.3. The Adaptation Gap and Remaining Issues

The research results show that although indigenous knowledge continues to play a crucial role in supporting livelihoods and adaptation to climate change, the effectiveness of this knowledge system is revealing significant limitations in the context of rapidly changing environmental and socio-economic conditions. One of the clearest manifestations is the emergence of an “adaptation gap,” reflected in the disparity between awareness of climate risks and the actual response

capabilities of households. Survey data shows that approximately 62% of households are clearly aware of the increase in extreme weather events, while only about 38% of households assess current adaptation measures as effective. This disparity reflects a significant gap between the level of awareness and the ability to act, indicating that understanding risks does not equate to the ability to respond effectively in practice.

A key factor contributing to the adaptation gap is the declining reliability of traditional environmental indicators. Approximately 45% of households believe that familiar indicators such as rainfall timing or crop growth cycles are increasingly difficult to predict, while only about 41% maintain high confidence in traditional practices for production decision-making. This suggests that the knowledge base based on long-term observation is being significantly impacted by climate change, increasing uncertainty in decision-making.

Besides environmental factors, socio-economic changes also contribute to widening the adaptation gap. Approximately 36% of households reported prioritizing short-term income-generating activities, even if these activities may conflict with traditional resource management conventions. Simultaneously, approximately 33% of households perceived that current state-mandated forest management regulations overlapped with or were not entirely compatible with local practices, diminishing the regulatory role of indigenous institutions.

Furthermore, resource disparities among households exacerbated the unevenness in adaptation capacity. Households with mixed livelihoods tended to adopt more adaptation measures, with approximately 64% of households in this group implementing two or more measures, compared to 49% in the purely agricultural group. This suggests that adaptation is not only dependent on knowledge but also linked to the degree of livelihood diversification and access to resources.

Overall, the results indicate that indigenous knowledge, while still playing a crucial role in livelihood systems and adaptation, is facing increasingly evident limitations. The adaptation gap emerges as a structural feature of highland socio-ecological systems, reflecting the incompatibility between existing adaptive capacity and the increasing variability of the environment. These findings highlight the need to consider indigenous knowledge not as a complete solution, but as a component that should be supplemented by institutional and policy resources in broader adaptation strategies.

4. Discussion

The results of this study provide empirical evidence that indigenous knowledge not only acts as a set of environmental practices, but also functions as a socio-economic governance system shaping the livelihoods and adaptive responses of highland communities. This finding is consistent with the approach of Fikret Berkes (2012), which emphasizes that indigenous knowledge should be understood as an integrated system encompassing knowledge, institutions, and practices, rather than just isolated technical experience. In the case of the Dao community in Lai Chau, customary practices related to forest use and livelihood organization show that indigenous knowledge truly plays a role in regulating behavior and resource allocation at the community level.

At the same time, the results also reinforce Elinor Ostrom's (1990) arguments on common resource governance, especially in the context of informal institutional systems that can effectively maintain resource sustainability. Practices such as spatial and temporal restrictions on exploitation, or community regulations on forest use, reflect the existence of governance principles compatible with local conditions. However, unlike ideal models of common resource governance, this study shows that indigenous institutions do not exist in a stable state, but are strongly affected by external changes, including market pressures and policy interventions.

A key contribution of the study is clarifying the relationship between indigenous knowledge, livelihoods, and adaptation in the context of climate change. The results show that indigenous knowledge supports the diversification of livelihoods and allows communities to flexibly adjust production activities, consistent with previous studies on adaptation based on local experience (Smit & Wandel, 2006). However, the study also indicates that adaptability depends not only on knowledge but also on access to resources and the degree of livelihood diversification. This is consistent with the argument of W. Neil Adger (2006), who argues that adaptability is the result of the interaction between social, economic, and institutional factors, rather than just a matter of perception.

In particular, the concept of the "adaptation gap" is clearly demonstrated in this study, where there is a significant discrepancy between the perceived risk and the actual response capabilities of households. This finding is consistent with recent studies on socio-ecological systems, in which Carl Folke et al. (2010) emphasize that existing knowledge and institutional systems may become insufficient to cope with the increasing speed and scale of environmental change. In the context of Lai Chau, the declining reliability of traditional environmental indicators, coupled with increasing climate uncertainty, has weakened the foundation of experience-based adaptation strategies. Furthermore, the study

also reveals the increasingly complex role of socio-economic factors in shaping adaptation capacity. The rise of commercial economic activities and the overlap between formal and informal governance systems have altered resource use dynamics, thereby impacting the effectiveness of indigenous knowledge. This aligns with Frances Cleaver's (2002) view that local institutions are always shaped by broader power relations and social contexts, rather than existing as stable and homogeneous structures.

From the above analysis, this study suggests that indigenous knowledge should not be considered a complete solution for climate change adaptation, but rather should be placed in a complementary relationship with institutional and policy resources. Integrating indigenous knowledge into formal adaptation strategies can help enhance relevance to the local context while overcoming limitations related to resources and information. However, this process needs to be carried out cautiously to avoid undermining existing indigenous governance systems.

While the study provides important contributions, some limitations must be acknowledged. First, the scope of the study, focusing on a specific community, may limit the generalizability of the results. Second, the survey data is primarily based on household reports, which may be subject to subjective factors. Furthermore, the study did not fully consider long-term factors such as policy changes or market trends, which could continue to shape the relationship between indigenous knowledge and adaptation in the future.

5. Conclusion

This study clarifies the role of indigenous knowledge as a socio-economic governance system in shaping forest-based livelihoods and supporting climate change adaptation for the Dao ethnic community in Lai Chau province. The results show that indigenous knowledge not only regulates resource use through customary practices and community institutions, but also contributes to promoting livelihood diversification and enhancing resilience in responding to environmental changes. Through an integrated approach of governance, livelihoods, and adaptation, the study provides empirical evidence demonstrating the strong link between local knowledge systems and the resilience of highland communities.

The results also indicate that the effectiveness of indigenous knowledge is facing increasing challenges under the simultaneous impact of climate change and socio-economic transformations. The declining reliability of traditional environmental indicators, coupled with the disparity between risk perception and response capacity, has revealed an adaptation gap at the household level. This finding suggests that indigenous knowledge, while still important, is no longer sufficient to ensure adaptation in a rapidly changing and complex context.

The main contribution of this study lies in reconceptualizing indigenous knowledge as a dynamic governance system, while clarifying the emergence of adaptation gaps in mountainous socio-ecological systems. Based on this, the study suggests that integrating indigenous knowledge with institutional and policy resources is necessary to enhance adaptation in the context of climate change. Future research needs to broaden the spatial and temporal scope and further examine the role of institutional, market, and policy factors in shaping the relationship between indigenous knowledge and adaptation.

Compliance with ethical standards

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Disclosure of conflict of interest

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