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Adaptation to Climate Change: Does Traditional Ecological Knowledge Hold the Key?

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Abstract: The traditional knowledge of indigenous people is often neglected despite its significance in combating climate change. This study uncovers the potential of traditional ecological knowledge (TEK) from the perspective of indigenous communities in Sarawak, Malaysian Borneo, and explores how TEK helps them to observe and respond to local climate change. Data were collected through interviews and field work observations and analysed using thematic analysis based on the TEK framework. The results indicated that these communities have observed a significant increase in temperature, with uncertain weather and seasons. Consequently, drought and wildfires have had a substantial impact on their livelihoods. However, they have responded to this by managing their customary land and resources to ensure food and resource security, which provides a respectable example of the sustainable management of terrestrial and inland ecosystems. The social networks and institutions of indigenous communities enable collective action which strengthens the reciprocal relationships that they rely on when calamity strikes. Accordingly, the communities maintain their TEK through cultural festivals and oral traditions passed from one generation to another. TEK is a practical tool that helps indigenous communities adapt to climate risks and promotes socio-ecological resilience, which upholds social empowerment and sustainable resource management.

Keywords: traditional ecological knowledge; traditional knowledge; local knowledge; indigenous knowledge; climate change; climate change adaptation; adaptation; resilience; socio-ecological systems; indigenous people

1. Introduction

The climate warming trend is explicit and now well documented in many studies conducted by researchers. Over the past few decades, the Earth has experienced rapid warming [1] with record high temperatures occurring in the last decade alone [2]. Human activities are the primary drivers of climate change as they contribute to more than 95 percent of the rapid temperature rise [3], especially due to the burning of fossil fuels, deforestation and land-use changes that emit greenhouse gases. The impact of global warming is evident across the world and is projected to become even more disruptive in the future [4,5]. In addition to mitigation action to reduce the extent of warming, it is imperative to adapt to the climate change that already exists. Adaptation, however, has become more difficult due to the uncertainties caused by the effects of climate change; therefore, it requires further intervention on many levels [6].

In response to this, indigenous people and their traditional ecological knowledge (TEK) have gained more attention due to their ability to address climate change at the grassroots level [7]. A growing body of research and global policy debates highlight how this knowledge system could contribute to climate action under Sustainable Development Goal (SDG) 13 and life on land in SDG 15 by detecting climate change, responding and adapting to its impact, thereby supporting global adaptation actions. Western scholars define TEK as "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relation of living beings (including humans) with one another and with their environment" [8] (p. 1252). Indigenous communities, on the other hand, have their own definition of TEK, which represents the complexity of their cultural knowledge systems. In essence, they express TEK as a "way of life"; rather than just knowledge about how to live, it is about the actual living of life [9] (p. 78). TEK is, therefore, an important expression of the indigenous culture and it is inextricably linked to their traditions. Their knowledge and management are about the values that shape and facilitate their responses to the dimension of global climate change [10]. Hence, despite being the worst affected by climate change, indigenous people's TEK responses to local-level climate variations make significant contributions to adaptation [11]. For indigenous people, TEK is the root of their resilience, i.e., their capacity to adapt to environmental change and uncertainties based on an in-depth understanding of the land [12]. Although they only represent five percent of the world's total population [13], indigenous communities hold roughly a quarter of the planet's land area that includes many of the world's biodiversity hotspots [14]. This has made them ideal custodians of the landscapes and ecosystems which are essential in climate change adaptation [15]. Despite the fact that TEK is critical to successful climate adaptation, it remains one of the least understood aspects of modern climate change adaptation initiatives [16]. In the midst of rapid globalisation, indigenous communities have demonstrated their persistent capability to conserve ecosystem services and co-evolve with the natural world. However, these communities have become the victims of institutional and social discrimination [17], hence diminishing their roles in development and political discourse, including climate change. In essence, they were seen as the victims of climate change impacts, rather than agents of environmental protection [18], thereby causing their culture and knowledge systems to be neglected as well. Indeed, there has been little discussion of indigenous people's adaptation to climate change in Malaysia.

In an attempt to address this knowledge gap, we have developed a framework based on TEK components, resilience theory and socio-ecological frameworks to explore communities' adaptation to climate change in coupled socio-ecological systems (Figure 1). To develop human-centric adaptation solutions on the basis of sustainable ecosystem management, it is crucial to understand the relationship between humans and the biophysical sphere [19]. Socio-ecological systems are an interplay between humans and the biophysical environment which is increasingly recognised as a tool for conceptualising human–environment systems and developing methods of governance that enhance resilience [20,21]. Many western academics and non-indigenous authors define resilience as the capacity of human and natural systems to respond to extreme events by adapting, self-organising and learning [22,23]. Meanwhile, many authors describe TEK by breaking it down into several interconnected levels of analysis which portray TEK as a knowledge–practice–belief complex [24–26]. According to Berkes [27], the first level starts with empirical observation, the second level refers to management practices based on factual observation, the third level entails social organisation with sets of rules and codes of social relationships, and the fourth level completes TEK by shaping the perceptions which govern human–environmental relationships. In the present study, we describe these categories as (1) local knowledge of the environment, (2) land and resource management, (3) social networks and institutions and (4) worldview and belief systems. Resilience theory perceives TEK as the foundation of long-standing observation and responses to climate shocks and stresses; hence, it increases the capacity to manage disturbance [28].

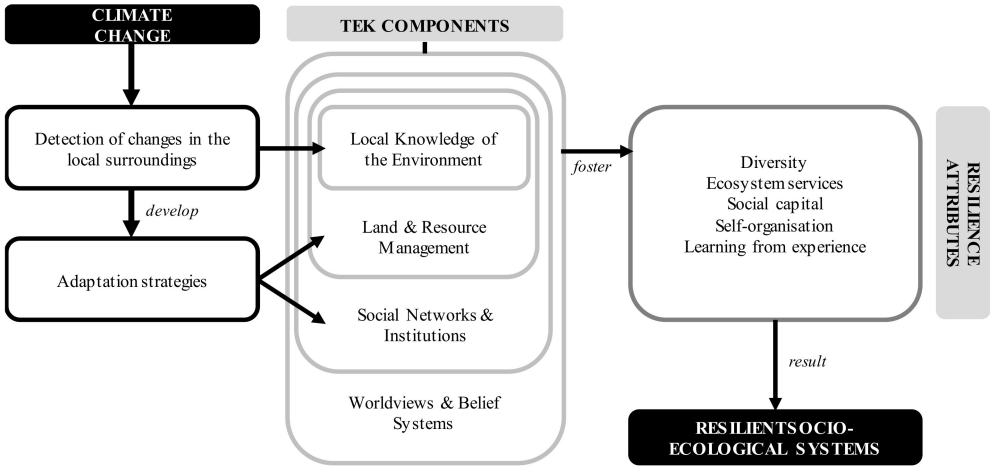

Figure 1. Conceptual framework.

In this framework, local knowledge of the environment includes the knowledge of flora, fauna, soil and landscapes as well as their classification, behaviour and distribution [25,27,29], which have been produced based on detailed observation of local ecosystems generated and transmitted over many centuries. Indigenous people conduct a careful observation of these elements to direct their subsistence activities across time and space, including agriculture, hunting, fishing and gathering [30–32]. Therefore, they are consistently aware of even the smallest changes in their surroundings. In the context of climate change, this local observation helps indigenous people to detect environmental changes, identify the impact of these changes, then develop strategies to cope and adapt. Customary land and resource management include adaptation strategies. Indigenous people's knowledge of natural resource use and strategies of terrestrial and marine management have evolved through adaptive processes [26,31]. Indigenous people often use practices based on management of the ecosystem and biodiversity to maintain crop yields and other livelihood resources in response to climate change (see for instance, Berkes et al. [8], McMillen et al. [26], Gómez-Baggethun et al. [28], Ingty [33], Magni [34]). These management systems have often developed through an understanding of the interrelation of various habitats and ecosystems [26].

Social networks and institutions depict the social mechanisms of TEK, which describe the behaviour and role of individuals or communities when facing climate perturbations. The central role of this facet of TEK is to promote self-organisation, an enabling function that underpins the feasibility of other functions [35]. A self-organised socio-ecological system is resilient if it is resistant to external alteration [36]. Finally, worldview and belief systems underpin the first three elements of TEK. These consist of values that shape adaptation behaviours [31,37] by supporting sustainable resource management and strengthening social cohesion [28], and these values have been transmitted from one generation to another [38]. This transmission often occurs in the form of folklore, taboos, stories, ceremony and rituals and other related cultural traditions [26,39]. These traditional methods of knowledge transmission promote long-term learning and adaptation, thus building the resilience of socio-ecological systems.

In this article, we provide a deeper understanding of the role of TEK in climate change adaptation in Malaysia and provide important insights into the theoretical, social and policy implications. In doing so, we analyse how communities view climate change based on their local observations, the adjustments that they make in terms of land and resource management, the interactions of the communities when facing disturbance and, finally, the values and practices that they have retained to enable adaptation across generations. The practical findings from this research will assist policymakers and other key stakeholders in Malaysia to formulate further actions to improve and promote effective place-based climate change adaptation. In addition to discussing the practical implications of TEK, this research

also investigates the theoretical dimensions of TEK as an emerging tool in climate change initiatives which provides support for the call to understand cultural dimension in climate change adaptation.

2. Materials and Methods

2.1. Study Area

We conducted our research in Sarawak, a Malaysian state located in northwest Borneo Island, bordered by Sabah to the northeast, Brunei to the north and Kalimantan to the south (Figure 2). With an equatorial climate, the temperature of Sarawak is relatively uniform throughout the year, 23 °C early in the morning to 32 °C during the day [40]. Sarawak, as in other parts of Malaysia, experiences two monsoon seasons; the northeast monsoon brings heavy rain between November and February, while the southwest monsoon from June to October is usually milder. The average annual rainfall is between 3300 and 4600 millimetres, which may vary according to locality [40]. With a total population of 2.5 million people, Sarawak has 25 ethnic groups that can be categorised into seven major ethnicities, namely, Iban, Chinese, Malay, Bidayuh, Orang Ulu, Melanau and others [41]. We chose Orang Ulu as our main research target because the majority of them still live in the remote interior of Sarawak and perform traditional practices in their daily activities. The Orang Ulu, who are also known as the "people of the interior", are made up of a few tribal groups in north-eastern Sarawak and their population ranges from 300 to over 25,000 people [42]. We chose three sub-ethnic groups of Orang Ulu, namely, the Lun Bawang, Sa'ban and Penan. Lun Bawang are wet rice agriculturalists who live in the highlands, the Sa'ban are upland rice agronomists living in the low land, while the Penan are the legendary hunter-gatherers of Sarawak who previously lived in the rainforest.

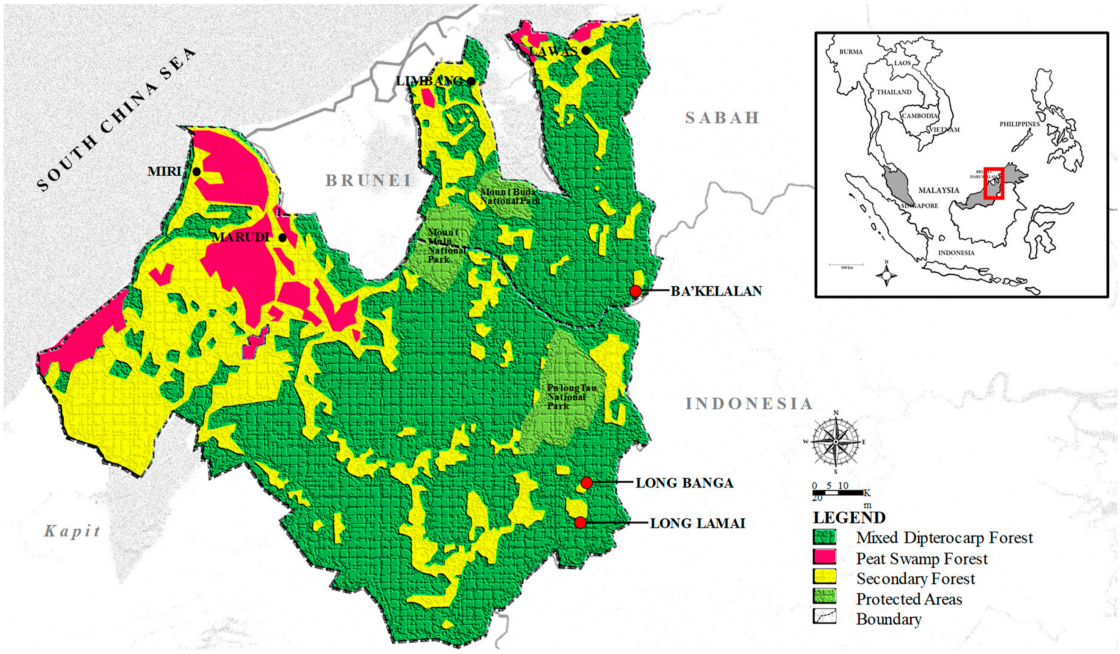

Figure 2. Location of the study area and its natural areas.

With a population of 1500 people, the Lun Bawang people are indigenous to the Ba'kelalan highlands, an isolated region located in the Limbang Division of Sarawak at an altitude of 3000 feet above the sea level. In the native language, Ba' means paddy field, whereas Kelalan means river. The Lun Bawang were one of the earlier settlers in the mountainous regions of central Borneo [43] and many of their traditional economical activities are related to rice cultivation, especially the *lati'ba'*. *Lati'ba'* refers to a traditional system of wet rice cultivation that is still maintained by the Lun Bawang people, where they incorporate water buffaloes into the farming system. The Lun Bawang are also

known as hunters and fishermen and, at the same time, practice animal husbandry such as rearing poultry, pigs and buffaloes.

The Sa'ban, on the other hand, are often referred to as a sub-ethnic group of Kenyah or Kelabit [44]. They comprise small communities in Long Banga, which settled in the most isolated area of the Baram River in the Marudi Division. Originally, the Sa'ban came from the Bahau watershed in East Kalimantan. They migrated to Sarawak around 1900 and continued until the late 1960s. The total number of the Sa'ban people is around 1100, which makes them one of the smallest sub-ethnic groups in Sarawak. Their increasing outmigration into the urban areas has reduced the number to about 500 people in Long Banga. All of these households are involved in diverse agricultural activities, but most are upland rice cultivators. Fishing and hunting for wild game is also a common activity for some individuals in the village.

Finally, the Penan are the renowned hunter-gatherers who used to live in the rainforests of the Sarawak interior. They are expert hunters who use silent blowpipes and poison darts for hunting. Their traditional staple food is *sago*, which comes from the core of a small palm tree. The majority of Penan communities were nomadic up until the 1950s. The transition in lifestyle was due to programmes promoted by the state government and foreign Christian missionaries to settle them into villages. One of the earliest Penan settlements is Long Lamai, with a population of approximately 580 people. Due to their isolation and sedentary lives, they have started to focus on an agrarian lifestyle where they cultivate rice and plant garden vegetables. However, they still rely on *sago* as their main staple as well as jungle fruits and hunting game.

2.2. Data Collection and Analysis

The TEK of indigenous groups was sampled during three fieldwork visits conducted in three villages between January and February 2019. In-depth interviews with local informants [45] and field observations were conducted. Field sites and communities were chosen based on the following criteria: (1) communities that still maintained traditional practices or economies, (2) resource-based livelihoods and (3) location of homes in a vulnerable environment [33,46]. Since the focus was on TEK, we targeted informants with direct experience in traditional practices including farming, hunting, gathering and forestry. The first person that we approached in each village was the headman to get background information about the study area, including population size, economic activity, history of the communities and other basic information. We used a snowball sampling technique [47] to identify further key informants. Overall we conducted 31 face-to-face semi-structured interviews with local informants (Table 1). Some of the answers were documented using a field notebook because there were a few informants who were unwilling to be tape-recorded due to unresolved disputes with the state government. The interviews took between 1 to 2 hours and were stopped if they drifted into repetitive information.

The questionnaire was structured into four main parts. Part One was designed to gather data on climate risks and threats affecting the livelihoods within the study area, environmental changes and understanding their weather forecasting and bioclimatic indicators. Part Two was related to their traditional strategies on land and natural resource management when they experience disturbances. Part Three was aimed at capturing the role of their social networks and institutions when a calamity strikes. The final part was used to understand their worldviews and belief systems related to their practices. The majority of respondents could speak and understand the Malay language (the official language of Malaysia) and only a few used English. Interviews were therefore conducted mostly in Malay. We also asked informants to translate a few words in their native language which represented the real expression of their communities rather than the official language. We used thematic analysis [48] to analyse qualitative data and identify themes in each of the research components. The global theme was built on the TEK framework.

Table 1. Demographic profiles of respondents.

	Lun Bawang	Sa'ban	Penan
Population	1500	500	580
Community Background	Wet rice agriculturalist	Upland rice agronomist	Hunter-gatherer and novice in agriculture
Staple Food	Rice	Rice	Sago
Sample Interviewed	10	10	11
Sex			
Male	8	6	8
Female	2	4	3
Age			
18–30	1	0	1
31–45	2	2	3
46–65	3	2	6
65+	4	6	1
Education			
None	0	6	4
Primary	1	1	3
Secondary	7	3	4
Tertiary	2	0	0
Main income			
Farming	7	8	9
Small business	2	2	2
Salaried work	1	0	0

3. Results

The traditional strategies for addressing climate change risks as identified by the Lun Bawang, Sa'ban and Penan are outlined in Table 2. The results were structured according to the four dimensions of TEK.

Table 2. Traditional ecological knowledge used to adapt to climate change as reported by local informants.

TEK Categories	Lun Bawang	Sa'ban	Penan
Local Knowledge of the Environment	**Bioclimatic indicators** • Observation of sky colour to predict daily rainfall. Formation of mist in the morning believed to be informative of temperature changes • Sightings of fruits to forecast the abundance of game **Changes observed** • Temperature of the environment has significantly increased. • The weather and seasons have become uncertain. **Identified impacts of changes** • Warmer temperatures cause frequent drought events which dry up the *lati'ba* (wet rice paddy) • Erratic rainfall causes flash flooding that erodes the *lati'ba*	**Bioclimatic indicators** • Division of the year into two seasons based on climatic patterns • Shape of the moon known as *"bliin teng"* was used as an indicator to plant seeds **Changes observed** • Temperature of the environment has significantly increased. • The weather and seasons have become uncertain. **Identified impacts of changes** • Droughts cause the land to dry up and inhibit the growth of the *padi iraang* (upland rice) • Wildfire events due to prolonged droughts • Uncertain weather and seasons makes rice farming difficult	**Bioclimatic indicators** • Division of the year into two seasons based on climatic patterns • Sightings of fruits and animals predict the coming of different seasons and forecast the abundance of game **Changes observed** • Temperature of the environment has significantly increased. • The weather and seasons have become uncertain. **Identified impacts of changes** • Drought events inhibit the growth of *inan parai* (rice plant) • Wildfire events due to prolonged droughts • Uncertain weather and seasons makes farming and hunting game difficult

Table 2. *Cont.*

TEK Categories	Lun Bawang	Sa'ban	Penan
Customary Land and Resource Management	• Integrated crop-animal farming is maintained through traditional *lati'ba'* system which promotes agrobiodiversity, food diversity and land resource management. • Intercropping of *kabun* (home garden) promotes heterogeneity • Diversified resource base through *kabun* and forest produce • Storage of resources in the *sulap padi* (paddy store) promotes food security • Preservation of forest area under local customary law	• The shifting cultivation of *padi iraang* allows the land to rest in 4–5 year cycles and maintains soil fertility • Intercropping of *éra* (home garden) promotes heterogeneity • Diversified resource base through *éra* and forest produce • Storage of resources in *paau padi* (paddy store) ensures constant flow of food over the years • Preservation of forest area	• The practice of shifting cultivation of *inan parai* in 4–5-year cycles allows vegetation to regenerate and maintains soil fertility • Intercropping of *pulah* (home garden) promotes heterogeneity • Diversified resource base through *pulah* and forest produce • Preservation of forest and resources through a set of customs known as *molong* encourage the community to preserve resources for future generations
Customary Social Networks and Institutions	• Preservation of family tree to promote social cohesion • Practising community pooling during a crisis for example *ngeruyung, gotong-royong, ngumum, musang* • Headman and church institutions enhance community engagement	• *"Si'sawai, Si'hnau, Si'lawai"* (one heart, one mind and one goal) is a socio-cultural philosophy that strengthens community kinship • Practice of *ledu'* to help those who have suffered from disaster • Church owns a rice farm called *mah maa' tempún* to help those who run out of food	• Community principle is to maintain good relationships with each other and remember obligations to each community member • Practice of *petulat* encourages resource sharing especially during hard times • *Pengepemung* remain central for collective problem solving and decision making
Worldview and Belief Systems	• Community value "kill only enough for food" as preservation principle • Value of uncertainty encourages disaster preparedness across generations through legendary folktales called *"beras dan harta"* • Cultural festivals *"Pesta Beras Adan"* encourage knowledge and cultural transmission	• Value of uncertainty encourages disaster preparedness across generations through *madei'* (advice from elders) • Knowledge and cultural transmission occurs through '*Ngkui'* festival	• Principle of "take only what you need" promotes resource preservation • Value of uncertainty encourages disaster preparedness across generations through *tesok* (advice from elders) • *"Dau Adet Penan"* is the cultural festival celebrated annually to transfer knowledge and tradition

3.1. Local Knowledge of Environment

The communities managed their subsistence activities such as agriculture, hunting and fishing by observing and predicting the variability of their climate and local surroundings. Traditional forecasts included observation of sky colour, temperature, moon phases, fruiting of fruit trees and the migration of animals. For example, the Lun Bawang reported that a reddish evening sky signals good weather the next day, characterised by a dry atmosphere with no precipitation. This condition is ideal for harvesting their *lati'ba'* because harvesting it during the rain will damage crops, thus reducing their yield. The Sa'ban and Penan, who cultivate upland rice, divided the year into two seasons based on climatic patterns; the "wet season" from October to February is characterised by heavy precipitation and the "dry season" from March to September is drier with higher temperatures. The agronomic cultivation of upland rice is heavily dependent on both seasons. The dry season is perfect for land preparation, whereas the wet season with heavy rains provides optimum conditions for the crop to

grow. The Sa'ban reported that they observed lunar phases to guide seed sowing. During the night in August, they look for the *"bliin teng"* or the "first quarter moon" as it indicates the perfect time to plant seed. Scientifically, the first quarter moon is considered fertile and wet due to the effects of tides on groundwater tables [49] exhibited during the moon's phases. The Penan monitor the presence and absence of fruits and pigs to predict the coming of different seasons and forecast the abundance of game. Apparently, the Penan monitor the massive migration of *"babui"* or Bornean bearded pigs (Sus Barbatus) in June and July which indicates that the fruit season is approaching. Following this event, the fruiting of forest trees signifies the beginning of the wet season, and when it stops, it means that the dry season is imminent. The Lun Bawang also explained that the shedding of ripe fruits during the harvest season in January indicates an abundance of bearded pigs in the jungle. The cold night temperatures in January also signal the spawning of fish in Ba'kelalan.

The majority of respondents, however, described that most of the bioclimatic indicators used to forecast weather and seasons were no longer reliable and were falling into disuse in the last 10 to 15 years due to changes in climate conditions. These indicators and adaptations all point to climate change issues directly impacting these indigenous groups. When they were asked about their perceptions of climate change, all respondents noted shifts in the climate and were aware of the impact these variations had caused. First, they reported that temperature of their environment has significantly increased. The Lun Bawang, for example, noted that the disappearance of the "misty morning" is a sign that the temperature is no longer cool. Apart from being vital for moisturising fields and gardens, mists make morning activities preferable during that time [50]. Disastrously, warmer temperatures cause frequent droughts and affect the wet rice fields. In the *lati'ba'* system, the rice must be kept flooded for most of its growth [51]. Therefore, prolonged droughts cause the river to dry up and prevent water from flowing into the *lati'ba'*, causing it to dry too. Planting rice is then difficult, which reduces food production. For the Sa'ban and Penan, prolonged droughts affected their upland rice and caused forest fires that lasted for months. During the event, all the crops and resources in the forest that they depend upon greatly were burned away, causing significant losses. The fires had destroyed the places where they get their food and damaged the rivers where they get the water supply. Since the communities live in isolated areas, market access is very limited. The nearest town that they can get the food supply is Marudi, which is located 230 km away from their home and can only be accessed by four-wheeled-drive (4WD) or Twin Otter plane. For the Penan, the forest has been their home for thousands of years, which holds food, water, traditional medicine and other resources. Most importantly, it holds their ancestral burial grounds, which create a link between past and present generations. Thereby, forest loss is impacting the cultural and spiritual life of its people. The Penan also stated that game was difficult to hunt during droughts as they could hardly detect any traces of the animals.

In addition, the communities consistently reported that the weather and seasonal patterns had become uncertain. In the past few decades, the prediction of weather was much easier when their seasonal planting calendar was based on fixed climatic patterns. Nowadays, this calendar was no longer reliable due to the shifts in rainfall and temperature regimes. There are abrupt variations to the rainfall; sometimes it is very low for an extended period, sometimes it is plentiful at an unexpected time. Accordingly, it affects food production and supply, especially among the Sa'ban and Penan who depend on this traditional calendar. The Lun Bawang also reported that heavy rainfall that occurs in a short period causes flash flooding, which erodes their paddy fields and thus destroys their livelihoods.

3.2. Customary Land and Resource Management

Climate change poses threats to those communities that are heavily dependent on natural resources and the monsoon climate for their agricultural practices. A few mechanisms were recorded that are used to respond to variations in climate and ensure an abundance of food and resource supplies throughout the year.

First, traditional agricultural practices were used as an adaptation to climatic conditions. These methods help to protect food supplies and make agriculture more resilient to climate change [52]. One of the techniques found was integrated crop–animal farming. The integration of animal husbandry with crop cultivation promotes agrobiodiversity, food diversity and resource management that strengthens the resilience of the agroecosystem to climate change [53]. The rice-buffalo co-culture system in Ba'kelalan is an age-old farming practice. The *lati'ba'* system is a wet rice farming technique used by the Lun Bawang for generations, which represents a close connection between people, buffaloes and the environment. For hundreds of years, the Lun Bawang worldviews have revolved around the *lati'ba'* that they cultivate and consume. It is not surprising that the Lun Bawang call themselves "the people of the wet rice fields" as they depend on the *lati'ba'* for livelihood and cultural significance. In fact, a person without the *lati'ba'* will not be recognised as part of the Lun Bawang. Basically, the *lati'ba'* is permanent terraced fields that surround the communities' settlements and a great example of efficient agricultural systems. The cycle of agriculture begins after the harvesting season. Water buffaloes are released into the fallow fields to clear all the remaining paddy straws until the next planting season. Consequently, the buffaloes soften the soil due to their movement in the rice field while their waste becomes an organic fertiliser which contributes nutrients, thus increases soil fertility. The Lun Bawang explained that this technique has helped them to maintain the rice yield of every plot for centuries, despite environmental stressors.

Another technique recorded is shifting cultivation. The Sa'ban and Penan cultivate upland rice, which only grows on dry soil and upland terrain using this agricultural system. Shifting cultivation is the most ancient agricultural system for maintaining soil fertility [54]. The basic concept of this method is the rotation of a long season of fallow, followed by a short season of farming. It involves the repeated shift of fields and the use of fire to remove natural vegetation [55]. The burning of dried vegetation at the beginning of this process helps to create nutrient-rich ash that improves soil fertility and eliminates weeds and pests from the area temporarily. Once rice harvesting has ended, the land is left to rest for four to five years, allowing the regeneration of vegetation in the area. With this method, both Sa'ban and Penan noted that the soil fertility is maintained persistently for years which promotes the growth of rice and produces a surplus yield.

The intercropping method was also found across the three communities. It involves the concurrent cultivation of more than one crop species on the same field [56]. Practically, this type of technique is applied in their integrated home gardens. They use different terms to refer to the garden. The Lun Bawang refer to it as *"kabun"* [57], the Sa'ban call it *"era"* [58] and the Penan use the term *"pulah"*. These home gardens occasionally included taro, sweet potato or yam. Some families also had papaya and banana trees and other vegetables. This farming system is very productive [59] because it reduces climate-driven crop failure as diverse crops have different climatic adaptability [60].

The second most important concept in their resource management strategy is diversification. Diversification helps to spread risks across spatial and temporal scales, thus increase food and resource security [61]. Food security, for example, is upheld through their home gardens which host other food varieties such as poultry, livestock and fish. The forests are also an option for obtaining wild animals, fish, vegetables and fruits. These options minimise risks, because if one food resource is damaged, the food supply in another region remains available.

Storage is also an important resource management strategy. One example of resource storage is the paddy store, which houses the surplus from each harvesting season. The respondents noted that one harvesting season could supply them with rice for up to three or four years. This paddy store is specially designed to avoid external threats such floods, rat attacks and others. It is a hut-like store made of wood, seven to eight feet above the ground which can only be climbed with a portable staircase, to prevent rats from getting inside the store. The body of the store is covered with zinc or plastics, while the pillars are coated with a slippery surface to inhibit rats climbing up. Storing resources is very important for these communities as it ensures a constant flow of food over the years and provides an emergency stock when disaster strikes, or if there is a poor harvest.

Finally, forest preservation was significant across all communities. Forests act as a buffer to protect paddy fields and provide alternative resources for the community, thus, they are maintained as a conservation area by customary law, with penalties imposed for violations. No human activities other than hunting are allowed within the forest, especially cutting and logging. The community applied value practices of "kill only enough for food" and "take only what you need", which have also become the basis of preservation behaviour to avoid over-hunting, thus ensuring an abundant food supply in the future. For the Penan, for example, the practice of *"molong"* or "to preserve" is an important aspect of their resource management. In general, preservation of the forest not only helps communities to adapt to climate change, but it also promotes resilient ecosystems by maintaining biodiversity.

3.3. Customary Social Networks and Institutions

Local institutions and networks play an important role in managing disturbances caused by climate and environmental stressors. In essence, coping with calamities is more effective when the communities respond collectively [62]. It requires everyone to know each other and care for one another in times of need. These communities are bonded by the cohesive forces of their family and kinship structure. Customarily, a family is shaped by a clans' relationships, which comprise father, mother, brother, sister, uncle, aunties, cousins and so on, which are also known as the extended family [63]. The Lun Bawang reported that the preservation of the family tree is their tradition which ensures everybody knows each other. The Sa'ban highlighted their socio-cultural philosophy, *"Si'sawai, Si'hnau, Si'lawai"* (one heart, one mind and one goal) [58] which unites and strengthens community kinship. Similarly, maintaining a good relationship between the communities has been a Penan principle for generations, and remembering their community as a whole is fundamental. These mutual bonds facilitate communication and provide relief during disasters, which are reinforced and maintained through festivals and regular visits. Despite modernisation, this principle still applies in all three communities to this day.

Communal pooling during hard times remains central in all three communities. For the Lun Bawang and Sa'ban, joining forces originated from rice culture. Farming either wet or dry rice is a strenuous task which requires the communities to pool their labour. Since the rice is planted on the same day, people rely heavily upon each other. A labour pool is needed for the heavy farming tasks like clearing/burning, planting and harvesting. *Ngeruyung*, *musang*, *gotong-royong* and *ngumum* are some forms of cooperation in the Lun Bawang community among those who need help on their farm. On some occasions, food is prepared as a reward once the work is over. *"Ledu"* is a term practised by the Sa'ban that refers to the help that is offered to those who have suffered from disasters (i.e., food shortages due to poor harvest). For the Penan people, living as nomads in the rainforests was a struggle and managing the uncertainties required them to support each other through the practice of *"petulant"*, a term that translates roughly as sharing. Even today, failure to share is the greatest offence in their society. *"Pengepemung"* is another collective action practised by the Penan which means "to gather". Once a month, they gather for communal work such as gotong-royong, meeting and other activities that require collective problem solving and decision making.

Local leadership was also identified as an important element for driving collective action and managing disputes. Headmen, village councils and the church institutions provide direction, and carry and transmit knowledge in all three communities. The headmen are formally appointed by the government based on the previous chieftaincy system and possess extensive knowledge of culture and customs of their communities. The respondents highlighted that, when hazards do occur, the first person they refer to is the headman. Accordingly, church institutions were significant within the community. The Orang Ulu are Christians, predominantly of the Sidang Injil Borneo or Borneo Evangelical Church (SIB). Even though professing Christianity has led to the elimination of some rituals (i.e., improper disposal of dead bodies and headhunting), some old practices have been maintained and infused with current religious teaching. For example, before Christianity, the communities will gather to perform a ritual to worship the spirit of the rice before they started to plant the paddy.

However, today, this practice is replaced with Sunday Mass, and it becomes the platform that informs the community of the dates they will collectively begin the rice planting. It brings the community together, thus strengthening their unity. These practices are common across all three communities. Interestingly in the Sa'ban culture, the church owns a *mah maa' tempún* [58], a rice farm cultivated by the community collectively, and the yield produced from the farm is given to those who run out of rice as a loan. This cooperation provides insurance against food crises and enhances their relationship by supporting their capacity to manage climatic and environmental change.

3.4. Worldviews and Belief Systems

Worldview and belief systems are at the root to the whole TEK system which shapes resource management and social relationships within the communities when they face a disturbance. From their traditional worldview, the natural world is one aspect of their lives and this interconnectedness creates a moral responsibility to live in harmony, respect and care for the environment. As mentioned, the value "kill only enough for food" and "take only what you need" remind them not to over-hunt, over-harvest or over-fish. Hence, species depletion is reduced, thus securing their resources in times of need.

Their adaptation strategies are also underpinned by the value of uncertainty, such that preparing for the worst is an obligation in their community. For example, the Lun Bawang expressed concern about *"tahun jahat"*, which is related to a bad harvest due to droughts or other disaster, causing reduced food supplies. The same concern was also found in the Sa'ban and Penan communities. The fear of this event is installed within each community and passed across generations through oral traditions. The Lun Bawang, for instance, have created a legendary folktale named *"beras dan harta"* or "rice and possessions". It explains the importance of protecting the rice field or the *lati'ba'*, which surpasses anything to be seen in Ba'kelalan. The need to prepare for an *iru* season (drought) encourages them to plant as many paddies as they can each year and make emergency stock, so that in the event of disaster, their food is secured. As for the Sa'ban and Penan, this knowledge is accumulated through *"madei"* (Sa'ban) and *"tesok"* (Penan), which refers to the advice obtained from their elders.

Communities also take part in cultural festivals based on traditional beliefs, which encourage respect for nature, reinforce identity and connect the community. For the Lun Bawang and Sa'ban, rice is central to their culture. Before Christianity, the Lun Bawang and Sa'ban perform rituals to summon the spirits of the rice after harvesting season to make the next harvest bountiful. The communities believe that the spirits will preserve the *lati'ba'* and *padi iraang* that support their livelihoods. For these communities, the rice is important that it must be nurtured for the next generations. Today, the rituals are replaced with annual thanksgiving festivals, the *Pesta Beras Adan* (Lun Bawang) and *Ngkui* festival (Sa'ban). Even though the rituals were no longer practice, the importance of preserving the rice is passed across generations during these events. The Penan, on the other hand, celebrate *Dau Adet Penan*. It is an annual festival that becomes the platform for the community to reinforce their history of being nomadic who rely a lot on the forests. The Penan feels that the history of their community will give them the strength to face today's challenges, especially in protecting the forests. In general, these cultural festivals are essential for communities to learn and preserve their culture. Apart from knowledge transmission, the festivals become places for sharing and exchanging information and resources, which strengthened social networks and maintained reciprocal relationships. Therefore, during hard times individuals then rely on these reciprocal relationships, thus ensuring the resilience of resource access, which is a fundamental need in the face of climate and environmental extremes.

4. Discussion

The intimate knowledge the Orang Ulu have of their local ecosystems revealed broad changes in the climate. The warming temperature perceived by these communities is consistent with the increasing temperatures recorded over the past decades, which have indicated a mean temperature increase per decade of approximately 0.14 °C for Sarawak [64]. The temperature increased sharply

in the years 1972, 1991, 1997–1998 and 2015–2016 due to a strong El Niño, with the 2015–2016 event being the worst [65]. In addition to rising temperatures, droughts were the primary concerns of these communities more than other disasters. Most of their coping strategies, including the fear of *tahun jahat* (a bad year), were related to drought management. Following this, the World Meteorological Organization reported that droughts have hit Sarawak numerous times since the 1970s due to a great decrease in rainfall associated with El Niño events [66]. It has also been predicted that droughts will hit Sarawak harder and for more prolonged periods in the future [67] with an expected increase temperature of 3.8 °C [68]. Judging from future climate change projections, the capacity of these communities to adapt to future climate stressors will be further challenged. Consequently, it requires advance intervention to manage risk in the face of climate change, especially long-term management to deal with significant uncertainties [69].

Our work also revealed that traditional strategies for managing the land and resources were the results of attempts to adapt to environmental stressors and uncertainties. Interestingly, this management system is consistent with the concept of adaptive management [8,70,71], an approach used to manage natural resources in the face of uncertainty [72]. An important aspect of ecosystem management for resilience is adaptive management to minimise uncertainty, which is the best approach for dealing with external shocks, given the complex non-linear dynamics of interconnected socio-ecological systems [73]. As mentioned above, these communities use practices that conserve ecosystem resilience, such as shifting cultivation systems to maintain forest cover, intercropping two or more crops in proximity to increase plant diversity, thus promoting resilience. This management system has subsequently created a vibrant mosaic of land use patterns within indigenous territory comprising patches of natural forest, managed forest, rotating fallow and permanent fields. It is a productive mosaic of habitats where the harmonious interaction of people and nature sustains biodiversity and provides humans with an ecosystem that supports various livelihoods and well-being [74,75]. This bio-cultural diversity is a major source of change response capacity which is strongly linked to community resilience [76,77] and needs to be further enhanced and promoted.

Furthermore, our findings indicate that the connections between these communities and their lands and forests are an important source of adaptation. When disaster strikes, for example, the lands and forests within the indigenous realm provide emergency resources such as wild animals, fruits, vegetables and other resources. Therefore, it is important for these communities to have access to these territories to obtain these resources. In this regard, the recognition of the collective rights to indigenous lands, territories and resources will support well-being of the indigenous communities and tackle climate change [78]. Our results corroborate previous research findings suggesting that secured land ownership, along with the rights to access, manage and extract natural resources from that land, are a pre-requisite of community resilience.

Anthropological scholars have provided important insights into how crisis and famine weaken social relations and reciprocity in traditional communities [79]. Our research, however, suggests that food scarcity and crisis promotes collective action by pooling resources and labour. This action is based upon the community culture, where the failure to retain this tradition is the greatest offence. Consequently, the social cohesion necessary for community resilience is maintained. In addition to social networks, the resilience of these communities is ascribed to indigenous institutions based on their own principles in response to the mutual support needed during disasters. This self-help approach has a strong influence on the community, which should be recognised by the government so that the marginalisation of these institutions can be avoided.

Another important result of our work relates to the role of worldview and belief systems in creating long-term community resilience by maintaining the culture of indigenous communities. Culture is essential as it shapes a community's values and how each community perceives the world and behaves accordingly [10]. Previous research has shown that folk beliefs support the sustainable use of natural resources which contribute to enormous increases in the pristine highland forest [80]. Our findings not only prove that their cultural values, which are sustained through oral traditions

and traditional festivals, have shaped the way the community governs their resources, but they also promote and maintain social cohesion among the communities. Therefore, the traditional way of life of these communities must be recognised and sustained to support resilient socio-ecological systems. Furthermore, unlike previous research which focused only on the role of religious ceremonies in supporting resilience to environmental extremes [28,81], our study found folktales and advice were other mediums of shared-belief systems that nurture community resilience. Folktales may have increased resilience by installing the value of "uncertainty" in an interesting and fun way within the community, especially among younger generations. Cultural festivals on the other hand, imitate the function of religious ceremonies, which enhance social cohesion.

5. Conclusions

Many studies have discussed TEK in the context of natural resource management [82–84]. However, the severity of global warming has resulted in an urgent need to include TEK in climate change initiatives. Since this alternative is now emerging, this study proposed an integrated framework that combines TEK components, resilience theory and socio-ecological frameworks to study the potential role of TEK in climate change adaptation. Based on this framework, we have shown that the knowledge system consists of a dynamic approach that contributes to socio-ecological resilience. Therefore, it is applicable to other place-based research that includes TEK in climate change studies. Unlike previous studies which only emphasised the importance of a few components of TEK, our work suggests that each component of TEK has a special role that should be given the same weight and importance.

Furthermore, as each component interrelates with all the others, the belief systems become the foundation that shapes their culture concerning the way they perceive and manage the environment and social relationship entirely. This component is often ignored in many place-based climate change adaptation practices; thus, we argue it is important to incorporate worldview and belief systems to capture the essence of adaptation behaviour within the community further. The reason for this consideration is due to the nature of the TEK, which is not a "one-size-fits-all" idea. TEK is developed through a continuous process that also includes spiritual and cultural elements of knowledge holders apart from multigenerational observations and skills. These aspects are more localised and specific to certain communities based on their social, economic and cultural needs. Hence, an adaptation plan without these elements is inoperative, which in turn lead to maladaptation to climate change [85]. Additionally, the study also extends the TEK, climate change and resilience literatures from a tropical region, specifically Malaysian Borneo, Sarawak. Hence, our work contributes a unique perspective because many previous studies have been based in polar and arid regions [31,86].

Our work also suggests that indigenous people are ideal environmental stewards. By using TEK, they have maintained sustainable traditional agricultural practices, traditional forest management and conservation practices, and traditional livelihoods within their territories. These practices are important for maintaining biodiversity and ecosystem services that help people adapt and mitigate climate change [87]. Consequently, the areas under an indigenous community's control are effectively conserved and can be considered as Indigenous and Community Conserved Areas, ICCAs [88]. Importantly, these ICCAs can be categorised as special areas for conservation [89] and should be recognised in national policies and practices, including land-use planning and conservation policies. Following legal recognition by the country's government, they will also be recognised or respected by private entities, such as logging and concession companies who sometimes encroach indigenous territories.

Additionally, any programme, project or policy related to climate change (e.g., REDD+) implemented on any indigenous lands should only be conducted with free, prior and informed consent [90] of the indigenous people. A prevalent problem that these people experience is the abuse of their rights to territories, lands and natural resources. In many countries, including Sarawak, the collective rights of indigenous peoples are poorly recognised [91]. However, despite the legally protected native customary rights (NCR) over land in Sarawak, denial of indigenous rights has happened due to a lack of law enforcement [92]. Such abuses of legal rights to land and resources,

including its use and management, have led to biodiversity loss among indigenous peoples. Our work will hopefully be an eye opener for the Sarawak government, and we urge them to consider and protect indigenous rights. This consideration is critical to avoid climate change maladaptation that threatens to burden the most vulnerable [85].

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