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Indonesia's Indigenous *Suku Anak Dalam*: knowledge for food and environmental sustainability

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This study provides an avenue for harnessing Indigenous knowledge to address contemporary environmental challenges by adopting traditional ecological knowledge and practices for food sustainability and environmental conservation. Based on primary field observations and interactions with the Indigenous *Suku Anak Dalam* (SAD) in Jambi Province, Indonesia, this study explores the significant potential of adapting Indigenous SAD traditional practices. These practices are deeply embedded and have great potential for adoption to address environmental challenges, including food insecurity and ecological degradation. These practices, which include selective harvesting, sustainable hunting, resource regeneration, and spiritual reverence for nature, align with key ecological theories and global conservation principles and demonstrate the wisdom of Indigenous knowledge in addressing contemporary environmental challenges by fostering biodiversity, maintaining ecological balance, and promoting responsible resource management. The emphasis on interconnectedness with nature and sustainable living strategies provides insights into achieving global sustainability goals, particularly in terms of food and environmental conservation. Integrating such Indigenous knowledge into modern conservation policies can yield culturally inclusive and ecologically effective solutions for global challenges. This study suggests that integrating traditional ecological practices into formal conservation frameworks can significantly improve biodiversity conservation and sustainable resource management. Policy-makers are encouraged to collaborate with Indigenous communities to develop inclusive environmental policies.

KEYWORDS

Indigenous knowledge, biodiversity conservation, food security, environment, sustainability

1 Introduction

The Indigenous community possesses a deep understanding of its environment, informed by cultural traditions and strong connections to local ecosystems. Their traditional knowledge plays a vital role in aligning human needs with environmental sustainability, thereby fostering ecological balance and resilience (Dudgeon and Berkes, 2003; Senanayake, 2006; Maila, 2007; Magni, 2017; Sultana et al., 2018; Priyadarshini and Abhilash, 2019). Recognizing the significance of Indigenous knowledge, this study examined the nexus of food and environmental sustainability derived from the traditional knowledge of the *Suku Anak Dalam* (SAD) on Sumatra Island, Indonesia.

Various studies indicate that Indigenous-managed lands encompass approximately 28% of the Earth's terrestrial surface while supporting 80% of global biodiversity (IPBES, 2019). For

example, in the Amazon rainforest, Indigenous communities manage approximately 35% of the land, and deforestation rates in these areas are significantly lower—up to five times lower—than those outside their stewardship (Walker et al., 2020). Furthermore, these lands serve as significant carbon reservoirs; Indigenous territories in the Amazon contain approximately 58 gigatons of carbon, which is crucial for mitigating climate change (Walker et al., 2020).

With respect to nature, Indigenous practices such as rotational farming and agroforestry have been essential for preserving biodiversity and addressing environmental challenges (Sharma et al., 2020; Malapane et al., 2024). Safeguarding Indigenous knowledge systems preserves cultural heritage and provides insights for global sustainable development (Sharma and Aulakh, 2023). Despite their critical importance, Indigenous knowledge and practices are frequently marginalized within formal environmental management frameworks (Al-Mansoori and Hamdan, 2023). Threats such as deforestation, industrial development, and inadequate land tenure policies jeopardize the ecological balance of these communities and their cultural and spiritual heritage (Garnett et al., 2018; Kennedy et al., 2023). These challenges underscore the pressing necessity for comprehensive research aimed at documenting and analyzing Indigenous knowledge systems, with particular emphasis on their substantial contributions to food security and environmental sustainability (Camacho et al., 2016; Burke et al., 2023).

In Indonesia, one of the most biodiverse countries, the Indigenous SAD demonstrate a lifestyle deeply intertwined with their forested environment (Basiago, 1995). Recognized for their seminomadic lifestyle, the Indigenous SAD participate in traditional activities such as hunting, foraging, and resource management, all of which are governed by customary laws (Colchester et al., 2004). Unfortunately, increasing challenges from massive plantations and industrial development not only threaten their livelihoods but also pose significant risks to their cultural heritage and traditional ecological knowledge (Sheil et al., 2002; Kennedy et al., 2023).

Nevertheless, Indigenous SAD practices exemplify sustainable adaptations that align resource utilization with ecological preservation. Accordingly, documenting the preservation of the SAD's traditional knowledge and practices is essential for protecting their cultural heritage and offering valuable insights for sustainable resource management and biodiversity conservation. Although prior research has acknowledged the role of Indigenous knowledge in sustainability, ongoing debates persist regarding effective methods for integrating these practices into modern sustainability frameworks (Camacho-Villa et al., 2021; Nelson and Shilling, 2018; Vijay Kumar, 2019; Druker-Ibanez and Caceres-Jensen, 2022; Gould et al., 2023). Moreover, evidence indicates that the displacement of Indigenous peoples not only jeopardizes their Indigenous knowledge but also exacerbates deforestation and environmental degradation (Kennedy et al., 2023).

This study aimed to investigate the traditional knowledge and practices of the Indigenous SAD in relation to food and environmental sustainability. By examining their sustainable practices, such as restrictions on cutting specific tree species, sustainable hunting methods, and forest foraging techniques, this research sought to underscore the potential of Indigenous knowledge systems to conserve biodiversity, enhance food security, and inform sustainable environmental management strategies. The study adopted a qualitative research approach grounded in Indigenous methodologies, centering

on the perspectives of the Indigenous SAD. By doing so, it provided a comprehensive exploration of their sustainable adaptations, considering the specific socioecological context and the wider environmental and social implications of their practices. Importantly, the Indigenous SAD are often subjected to a process of 'othering,' where they are labeled primitive or culturally backward by outsiders. The reality is that outsiders are comparing their lives, which are different from those of the SAD community, according to the perception of 'modernity,' defined by standardized housing, schools, livelihoods, public services, and administrations. Moreover, these external labels often manifest in terminology such as *Orang Rimba* ("people of the forest") or *Suku Kubu*, the latter of which carries negative connotations rooted in colonial and pejorative discourses. In contrast, the community members refer to themselves as *Suku Anak Dalam*, meaning 'people from inside the forest,' a term that reflects their identity as forest dwellers who are deeply connected to their ancestral land. This self-identification underscores their cultural autonomy and spiritual relationship with the environment. The discrepancy between internal and external naming reflects broader sociopolitical dynamics of marginalization and exclusion, which reinforce stereotypes and hinder equitable engagement with the Indigenous SAD (Sager, 2008).

Moreover, Indigenous knowledge systems, such as those practiced by the Indigenous SAD, are increasingly recognized as critical to the One Health approach, emphasizing the interconnected health of humans, animals, and ecosystems. Traditional ecological practices that maintain biodiversity, ensure sustainable resource use, and promote environmental stewardship align strongly with One Health principles (Pollowitz et al., 2024; Sudlovenick et al., 2024; Wingett et al., 2025).

2 Revisiting indigenous methodologies

Indigenous research methodologies emphasize culturally sensitive and community-centered approaches that honor Indigenous knowledge systems (Wilson, 2020). By integrating these methodologies into research involving the Indigenous SAD community, this study sought to respect their sovereignty and validate their ecological and spiritual knowledge within a global sustainability context. Adopting a participatory framework as outlined by Chilisa (2019), Indigenous SAD community members were engaged as coresearchers to ensure that their perspectives and priorities remained central to the research process. The study adhered to the OCAP principles—Ownership, Control, Access, and Possession—developed by the First Nations Information Governance Centre in 2004 to safeguard Indigenous SAD knowledge and reinforce their data sovereignty (Schnarch, 2004). This ethical framework was further supported by Kukutai and Taylor (2016), who underscored the importance of Indigenous data sovereignty in protecting Indigenous knowledge systems and fostering equitable collaboration.

The integration of Indigenous methodologies has demonstrated the potential to address global challenges. For example, the Zuni Mapping Project effectively combined oral traditions with geographic information system (GIS) technology to preserve cultural heritage and inform land use policies (Ferguson and Colwell-Chanthaphonh, 2006). Similarly, participatory biodiversity monitoring programs in Southeast Asia, as articulated by Moller et al. (2004), illustrated how traditional ecological knowledge could complement scientific

methods in addressing environmental issues. These examples underscore the potential of Indigenous research methodologies in creating sustainable solutions, a goal that this study aimed to replicate in relation to the Indigenous SAD.

However, despite their promise, Indigenous methodologies face systemic barriers. Kovach (2017) highlighted that Western academic institutions often undervalue Indigenous approaches, favoring frameworks rooted in quantitative and colonial perspectives. Furthermore, Wilson (2001) critiqued extractive research practices that exploited Indigenous knowledge without yielding tangible benefits for the communities involved. The present study aimed to address these challenges by employing culturally sensitive, decolonized methodologies that aligned with the priorities of the Indigenous SAD and enhanced their wellbeing.

This research underscores the importance of Indigenous research methodologies in the preservation of ecological and spiritual knowledge pertaining to the Indigenous SAD while contributing to the global sustainability discourse. By emphasizing relational accountability, participatory methodologies, and data sovereignty, this study exemplified an ethical and culturally sensitive approach to research. Furthermore, it aligned with the movement toward decolonizing methodologies, addressing systemic challenges and fostering equitable collaboration with Indigenous communities.

3 Methods

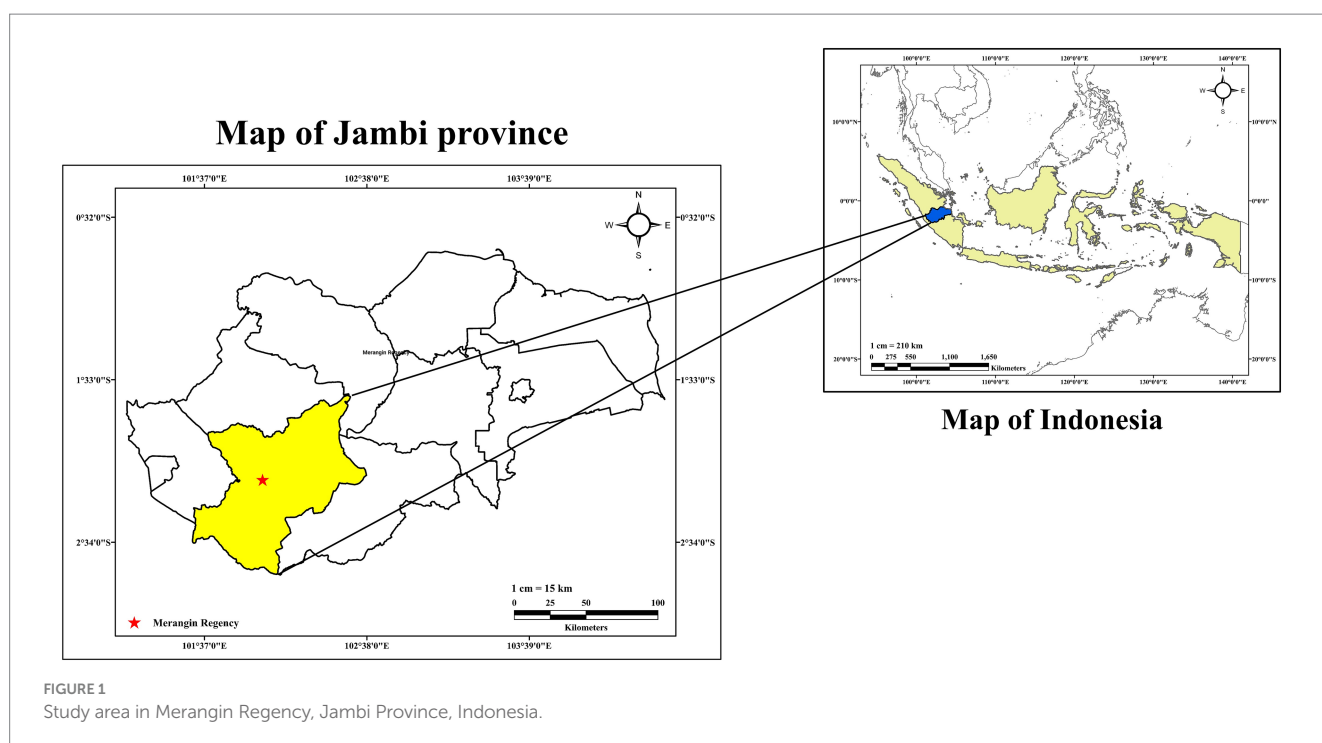
Using a qualitative method, this study utilized an Indigenous methodological approach to document and analyze the traditional knowledge of the Indigenous SAD and its implications for food and environmental sustainability. By employing an Indigenous methodology, the study emphasized participatory engagement, cultural sensitivity, and the amplification of Indigenous voices, thus

optimizing their involvement in the research (Kovach, 2017). Accordingly, the study adopted operational strategies based on primary data resources (Barnes, 2001) to address the challenges of accessing the marginalized Indigenous SAD group, with a focus on trust building and collaboration.

3.1 Study area

The *Suku Anak Dalam*, also known as the *Orang Rimba*, are Indigenous peoples native to the island of Sumatra, with primary populations concentrated in Jambi Province and smaller communities present in adjacent provinces such as South Sumatra. The study was conducted across four settlements of the Indigenous SAD, located in Merangin Regency, Jambi Province, Indonesia (see Figure 1). Geographically, Merangin Regency is located in the western part of Jambi Province. The topographical landscape is composed of lowland tropical rainforests, river valleys, and hilly terrains that are part of the Bukit Barisan Mountain range. Like most typical Sumatran landscapes, Merangin lies at elevations ranging from 100 to over 1,000 m above sea level. The weather in Merangin generally features a humid tropical climate, with average annual rainfall exceeding 2,500 mm, which supports rich biodiversity (Basiago, 1995). As a region defined by major water bodies, Merangin is home to the Merangin and Batanghari rivers, which are central to the livelihoods of the people (including the Indigenous SAD), serving as sources of water, fish, and transportation routes.

The total population of the Indigenous SAD in Jambi is approximately 200,000 people (Desamind.id, 2022). The study area was selected purposively because of field accessibility. The Indigenous SAD who participated in this study are semi-nomads since much of their traditional forest territory has been converted into palm oil and rubber plantations. In addition to the forest, most of the community lives in both



permanent and semipermanent settlements on the outskirts of villages as well as temporary settlements in plantation areas. Off-road vehicles were used to reach the Indigenous SAD areas during data collection.

3.2 Data collection and participants

During field visits, a series of in-depth interviews were conducted with 16 Indigenous SAD community members, including four *Tumenggung* (headmen), four *Wakil Tumenggung* (vice headmen), four *Induk* (wives of the *Tumenggung*), and four elders. In accordance with Indigenous customs, only individuals belonging to these four categories are permitted to share information with outsiders. Prior to meeting with the participants, the researcher was aware of the trust issues presented by the Indigenous SAD, resulting in their hesitancy to interact with outsiders. It appeared that the Indigenous SAD had experienced multiple disappointments due to unfulfilled promises to improve their livelihoods made by the government and other stakeholders. Furthermore, local communities harbored a negative stigma toward the Indigenous SAD, which discouraged them from interacting with outsiders.

To overcome these constraints, the researcher collaborated with trusted local intermediaries whom the Indigenous SAD considered *pemimpin* (leaders), one of whom was a schoolteacher. These two individuals had been engaging closely with the Indigenous SAD and advocating for their rights for decades. Their involvement helped foster trust, enabling meaningful interactions with the Indigenous SAD throughout the research activities.

Moreover, given the Indigenous SAD people's limited communication skills, the interviews were conducted patiently and repeatedly. There were instances where the hunting and foraging activities of the *Tumenggung* and *Wakil Tumenggung* often conflicted with scheduled meetings. As a result, each participant was visited 3–5 times, with each session lasting approximately 1–2 h, ensuring that rapport was built and that all research questions were addressed comprehensively. The interviews were conducted in Bahasa, Indonesia, with a Malay Jambi accent, and appropriate translation for research purposes was carried out. Data collection took place from December 2023 to May 2024. Breaks were held during Christmas, New Year, and the Indonesian presidential election. During these periods, the researcher participated in regrowing and rebreeding activities with the Indigenous SAD, extending the scope of fieldwork beyond data collection.

This research obtained approval from the Research Clearance Committee of Indonesia's National Research and Innovation Agency (BRIN), approval number 065/LI.04/HK.01.00/2024. Prior to visiting each site where the Indigenous SAD community resides, we ensured that proper permission was obtained from the subdistrict head (*camat*) and followed their recommendations to honor local communities and uphold the cultural values of the Indigenous SAD. Additionally, all research activities were conducted in a culturally appropriate and respectful manner, with guidance from Indigenous SAD leaders, and written informed consent to participate in this research was obtained from the participants.

3.3 Interview guide

The interviews began by asking participants to recall how they had learned to hunt wild boars, encouraging them to share

memories of successful hunts, the tools they had used, and how they had overcome difficulties when hunting had been more challenging. The interviews also explored traditional fishing methods, with a focus on techniques used in rivers, such as *lukah* (bamboo traps), and how the community had ensured the availability of fish for everyone. The interviews also included questions related to the maintenance of fish stocks, exploring how the community ensures the sustainability of riverine resources through selective fishing techniques.

The interview guide delved into forest foraging practices, asking what plants had been gathered and how people had identified which plants were safe to eat. It invited participants to reflect on times of scarcity and how the community had responded. Another line of inquiry examined the treatment of sacred trees, including stories about seeking permission from forest spirits before cutting a tree, and the significance of these rules in preserving cultural and environmental balance.

The participants were also asked how they had been taught to gather resources such as rattan and to reflect on their experiences of harvesting with family members. The questions probed into practices that had ensured resource sustainability. Land management was another focus, with questions about how communities had traditionally cleared land without damaging the forest, how land had been allowed to recover, and how decisions had been made regarding when and where to clear new areas.

A section of the interview guide explored the cultural tradition of relocating after a death in the community. The participants were asked about their experiences with this practice, including discoveries of new plants or animals in the relocated areas and how the practice might have supported environmental recovery. The guide also inquired about traditional health practices, especially how communities had responded when someone had been sick, including methods of care and isolation, and the lessons such practices had imparted.

Ceremonies that aligned with nature were also explored, particularly in relation to how they had taught community cooperation and respect for the forest. This exploration included questions about lessons from childhood and the role of storytelling in teaching environmental respect. The guide included a focus on rituals such as the *Tari Elang* (Eagle Dance), asking participants what actions or words had been used to thank spirits after a hunt or harvest and how such rituals had reinforced environmental stewardship.

River-related practices were also discussed, including traditional ways of keeping rivers clean and safe, materials that had been used for bathing and washing, and rituals that had been held by the river. The interview guide further investigated periods when the community had refrained from working in the forest for sacred reasons, exploring what had been learned during those times and how such pauses had helped the forest regenerate while deepening community bonds with nature.

Finally, the participants were asked to recall stories from their elders about the forest—especially those that had taught lessons on living in harmony with nature—and how these stories had been shared with the younger generation. The final questions focused on how the ancestors had instilled a sense of environmental responsibility, including what had happened when community rules were broken and which teachings had been most critical for ensuring the health of forests and rivers for future generations.

3.4 Data analysis

A qualitative analysis method was used, specifically employing thematic analysis as outlined by Braun and Clarke (2006), to interpret the data gathered from in-depth interviews with members of the Indigenous SAD community. This approach provided an in-depth understanding of the Indigenous SAD's perspectives on food and environmental sustainability and their relationship with nature.

The analysis began with the transcription of the interviews, followed by coding to identify key themes, concepts, and practices that emerged from the Indigenous SAD's descriptions of their knowledge and practices regarding sustainability. Coding was performed inductively, meaning that codes were derived directly from the data rather than from preconceived categories. NVivo software (version 14) was used to assist in organizing and analyzing the qualitative data, allowing for a more efficient and systematic approach to data coding and theme identification.

Through thematic analysis, recurring themes were identified across the interviews, with a focus on practices such as hunting, foraging, resource management, and spiritual rituals. The analysis also highlighted the ethical principles of the Indigenous SAD, such as their belief in balancing human needs with environmental health, and emphasized themes related to ecological cycles, food security, and sustainable resource use. These themes were then interpreted within the cultural context of the Indigenous SAD, considering how their knowledge of food and environmental sustainability was embedded in their beliefs.

4 Results

The Tumenggung (T), Wakil Tumenggung (VT), Induk (I), and elders (E) who engaged in this research were assigned a code, with each group consisting of four people, hereinafter referred to as A, B, C, and D. The following themes provide an overview of various aspects

of the traditional knowledge and practices of the Indigenous SAD, particularly in relation to food and environmental sustainability (Tables 1–4).

4.1 Traditional hunting and foraging practices

Hunting practices among the Indigenous SAD are carried out via simple tools and knowledge that had been passed down through generations. For example, one of the Tumenggung explained:

“Oh well buru (hunting) was part of our identity; it was our life! Hahahaha ... (laughing). Since childhood, we had been taught to hunt. Our hunting tool was also special; we called it Kujur (wooden spear).” (T-A)

“Let's say when we aimed to hunt wild boars. We weren't reckless or else we could have been bumped by them (wild boars) from the back. Hahaha ... (laughing). So, our trick was that we followed their (wild boars') footprints (track) in the bush. When we found an apparent track, we set up simple traps along the paths they frequently traversed. When a boar entered the trap, naaah (an excitement expression) that was the time we used the Kujur to capture it!” (T-A)

In addition to hunting wild animals, techniques for hunting smaller animals, such as squirrels and birds, are also learned from an early age. Another Tumenggung shared his experience:

“You know what more about hunting? We also hunted small animals, like birds. Also ... hmmm ... (trying to memorize) what was it called? Yes ... the squirrels! For small animals like that, we used blowpipes (blowguns with small darts). Usually, we tried to catch them during the fruit season while we gathered various types of forest fruits.” (T-B)

TABLE 1 Traditional hunting and foraging practices.

Aspect(s)	Knowledge and practices	Implications for food and environmental sustainability
Hunting practices	- Use of kujur (wooden spear) for wild boars, with traps set along animal trails. - Use of blowpipes for squirrels and birds, with darts coated in natural poison from ipuh tree sap.	Food sustainability - Targeted use of kujur and blowpipes prevented overhunting and ensured sustainable food sources. - Collection of forest durian, jernang resin, and mushrooms diversified food sources sustainably. - Traditional methods made toxic tubers like gadung edible, utilizing otherwise wasted resources. - Smoke-driven honey collection protected bees while providing a renewable food source.
Forest foraging	- Collection of wild fruits such as forest durian and jernang resin. - Medicinal use of pasak bumi roots and sungkai leaves. - Mushroom foraging (e.g., wood ear mushrooms, oyster mushrooms) in the rainy season.	
Processing practices	- Toxic tubers (e.g., gadung, wild bengkuang) were processed by slicing, soaking in river water, and sun-drying. - Forest honey was harvested using smoke to drive bees away without harm.	Environmental sustainability - Practices such as foraging and selective hunting supported ecosystem balance and species diversity. - Use of biodegradable materials (e.g., ipuh sap, bamboo) minimized environmental harm. - Bee-friendly honey harvesting ensured ongoing ecosystem pollination services. - Hunting, fishing, and foraging aligned with natural cycles, maintaining environmental health.
Fishing techniques	- Use of lukah (bamboo fish traps) in calm river currents at night. - Tuba roots were used as a natural toxin to stun fish for selective harvesting.	

TABLE 2 Local wisdom in forest resource management.

Aspect(s)	Knowledge and practices	Implications for food and environmental sustainability
Forest resource management	- Customary law prohibited people from entering sacred forestry areas and cutting sacred trees. - Only old or nearly dead trees were used for wood. - Rituals were performed to worship the forest's spirits and seek permission.	Food sustainability - Rotating hunting areas prevented overhunting, allowing animal populations to recover and ensuring a continuous food supply. - Nonburning land-clearing methods-maintained soil fertility and ensured long-term agricultural productivity. - Leaving resources like honey and fruits for animals fostered ecosystem balance, ensuring food sources were replenished.
Rattan harvesting	- Rattan was cut carefully without removing the roots. - Younger stems were left to regenerate. - Rattan was used for baskets, ropes, and selling.	
Rotational hunting	- Hunting areas were rotated to allow animal populations to recover and reproduce. - Overhunting in a specific area was avoided.	
Land-clearing practices	- Land was cleared without burning. - Only shrubs were removed; large trees were preserved. - Cleared land eventually reverted to forest.	Environmental sustainability - Prohibition on cutting sacred trees and harvesting only old or dying trees conserved forest ecosystems and biodiversity. - Sustainable harvesting practices supported forest regeneration and prevented resource depletion. - Using plant-based dyes minimized pollution and preserved the natural environment. - Preserving large trees and allowing cleared land to revert to forest supported carbon sequestration and habitat restoration. - Clean rivers and the use of natural soap prevented chemical contamination, safeguarding aquatic life and ecosystems. - The belief in sharing with nature reinforced conservation ethics and supported biodiversity.
Natural dye production	- Leaves and tree bark were used for dyes (e.g., guava leaves for green, mahogany bark for red).	
River conservation	- Rivers were kept clean; no chemicals were used. - Natural soap made from <i>lerak</i> fruit was used for washing and bathing.	
Sharing with nature	- Always spared some resources (e.g., honey, fruits) for animals. - Believed that sharing with nature brought blessings.	

“Oh, you didn’t know the blowpipes? Hahaha (laughing), it was just a bamboo tube, with darts that we tipped with sharp points coated in natural poison. We derived the poison from the sap of the Ipuh tree.” (T-B)

The hunting practices of the Indigenous SAD, as described by Tumenggung A, highlight the use of *Kujur* (wooden spears) to trap wild boars through simple yet effective traps. This method reflects an understanding of animal movement patterns and the ability to employ efficient hunting techniques that minimize environmental impact. Moreover, Tumenggung B described techniques for hunting smaller animals, such as squirrels and birds, using blowpipes made from long bamboo and small arrows tipped with natural poison derived from the sap of the *Ipuh* tree. The use of these tools demonstrates the skilled utilization of natural resources and an adaptive approach to ecological cycles, particularly during the fruiting season. These two hunting practices underscore the connection between the Indigenous SAD and the forest, which serves as their source of livelihood. Their reliance on natural materials, such as bamboo and *Ipuh* tree sap, illustrates a relationship with the environment that is rooted in traditional knowledge passed down through generations. One of the vice Tumenggung was also skilled in processing forest products and explained:

“Oh ... I remembered times when I did Meramu (concocting) from many forest plants. Old people like me did this task the most, I didn’t know why though ... hehehe (smiling). So, for example, when

I Meramu for medicinal purposes, I identified plants like Pasak Bumi roots to enhance stamina, and sometimes to reduce fever, I picked Sungkai leaves. I only took a small portion and left the rest behind.” (VT-D)

“Unlike Meramu, all of us, young and old, foraged together when we searched for wild fruits. My favorite was forest durian and jernang (dragon’s blood resin).” (VT-D)

Additionally, mushroom foraging is one of the primary activities during the rainy season, as stated by one of the *Induk*.

“We were familiar with many types of mushrooms that grew in the forest. Not all mushrooms were edible, so it was essential to identify which ones were safe. So, we usually foraged for mushrooms after rainfall. Forest ear mushrooms and oyster mushrooms were among our favorites. We cooked them alongside other forest vegetables, such as ferns and singkil leaves.” (I-A)

The skills and knowledge demonstrated by Vice Tumenggung D in utilizing wild fruits such as forest durian and *jernang* reflect the community’s understanding of local flora. This understanding was further supported by their traditional medicinal knowledge, including the use of *pasak bumi* roots to enhance stamina and *sungkai* leaves to reduce fever. Their ecological awareness is evident in the principle of sustainable harvesting, ensuring that some resources are left to maintain environmental balance. Moreover, the ability to identify fungi, as explained by *Induk* A—particularly edible varieties such as

TABLE 3 Social and ecological sustainability through tradition.

Aspect(s)	Knowledge and practices	Implications for food and environmental sustainability
<i>Melangun</i> (relocation)	- Families relocated after a death to honor the spirit of the deceased and allow the forest to regenerate. - The journey helped discover new resources.	Food sustainability - During <i>melangun</i>, families discovered new resources, promoting sustainable use of diverse forest foods. - Teaching children not to disturb bird nests or collect wild eggs ensured the survival of bird populations and the availability of future food sources. - Providing food to ill individuals while isolated prevented the spread of disease, ensuring community wellbeing and food security.
<i>Besсандongon</i> (isolation)	- Ill individuals were isolated in a separate space. - Families provided food from a distance to prevent the spread of disease.	
<i>Bebalai</i> (marriage tradition)	- Celebrated with dances, songs, and teachings on forest conservation and community cooperation.	Environmental sustainability - <i>Melangun</i> after a death allowed the forest to regenerate, fostering ecosystem recovery and biodiversity. - Celebrations incorporated teachings on forest conservation, reinforcing sustainable environmental practices. - Instilling respect for customary conservation rules helped protect wildlife and their habitats. - The belief in life's interconnectedness promoted holistic conservation efforts, ensuring that ecosystems remained balanced and resilient.
Early education	- Children were taught not to disturb bird nests or collect wild eggs. - Lessons included customary rules and the reasoning behind conservation practices.	
Interconnectedness of life	- Believed that all forest life is interconnected. - Damaging one part affected the entire ecosystem.	

jamur kuping (wood ear mushrooms) and forest oyster mushrooms—illustrates ecologically grounded skills passed down through generations. The practice of collecting mushrooms after rainfall highlights an understanding of natural cycles and harvesting periods. Nevertheless, certain forest products require special processing before they can be consumed. One of the Elders explained the method for processing toxic tubers:

“Well, not everything could be consumed directly; we could get food poisoning if we didn’t know how to cook it properly, ha ... ha ... ha ... (laughing). Do you know *Gadung* (*dioscorea*)? That plant had toxins, you know. So, what we did was thinly slice it, then soak it in flowing river water. Right ... after several days, the toxins would be gone, and then we could dry it under sunlight before we ate it.” (E-C)

Another Elder shared a method for harvesting forest honey:

“Forest honey was one of the most valuable natural resources. We located beehives in tall trees. To harvest the honey, we produced smoke from dry leaves to drive the bees away without harming them.” (E-D)

Interviewees also emphasized the importance of utilizing all edible parts of animals and plants. For instance, by detoxifying tubers like *gadung* and carefully harvesting honey without harming bees. The processing of toxic tubers, as described by Elder C—such as *gadung* and wild *bengkuang*—involved slicing them thinly, soaking them in running river water for several days, and sun-drying them. This process demonstrates the community’s understanding of how to remove harmful substances, reflecting their adaptation to an environment that offers natural food resources requiring specific methods of preparation. Moreover, the forest honey harvesting method explained by Elder D, which involves the use of smoke from dried leaves to drive bees away without killing them, illustrates a deep respect for the sustainability of bee populations and their habitats. These two practices highlight the balance between the use of forest

resources and the preservation of ecosystems. Despite naturally foraging their vegetative food sources, the Indigenous SAD also apply local knowledge in fish-catching practices. One of the vice *Tumenggung* explained:

“To catch fish in the river, we used bamboo traps called *Lukah*. These traps were placed in calm river currents at night and retrieved in the morning. Occasionally, we also used *tuba*, a natural toxin derived from *tuba* roots. This toxin merely stunned the fish, allowing us to collect those of adequate size.” (VT-B)

Vice *Tumenggung* B’s explanation of fish-catching methods using *Lukah* (fish traps) and *Tuba* (natural fish poison) illustrates how local knowledge is employed to optimize catches without harming the ecosystem. The placement of *Lukah* in calm river currents at night demonstrates the Indigenous SAD’s understanding of fish behavior, including their movement patterns and preferred habitats. Furthermore, the use of *Tuba* roots as a natural poison reflects an intricate knowledge of local plant properties, as this toxin temporarily stuns the fish without damaging the aquatic habitat or other organisms.

4.2 Local wisdom in forest resource management

The Indigenous SAD adhere to local wisdom passed down from generation to generation. Several teachings and beliefs related to their approach to protecting the forest are embedded in their culture and guide how they manage forest resources. For example, the management of forest resources are carried out with strict adherence to customary laws. One of the elders explained:

“One thing that many people didn’t know. Our *Suku* (tribe) had strict customary rules about cutting down trees. We could not just cut down trees whenever we wanted, ooooh (serious expression), it was very prohibited.” (E-A)

TABLE 4 Spiritual connection with forest ecosystems.

Aspect(s)	Knowledge and practices	Implications for food and environmental sustainability
<i>Tari Elang</i> (Eagle Dance)	- Dance mimics an eagle, symbolizing strength and freedom. - Performed to honor forest spirits and teach respect for nature.	Food sustainability - Permission-seeking and expressing gratitude before and after hunting promoted sustainable hunting practices that prevented overexploitation of animal resources. - Involving children in rituals to express gratitude for forest resources reinforced sustainable food practices across generations. Environmental sustainability - The dance honored forest spirits and fostered respect for wildlife, promoting biodiversity conservation. - Protecting sacred trees prevented deforestation and preserved vital forest ecosystems. - Teaching children conservation values through rituals ensured long-term environmental stewardship. - Emphasizing cleanliness during purification ceremonies encouraged responsible water use and river conservation. - Halting activities during sacred periods allowed ecosystems to recover, fostering ecological resilience. - Rituals performed after disasters or illnesses highlighted the importance of addressing ecological imbalances, thus generating and preserving harmony with nature.
Sacred trees	- Certain trees were believed to be the home of ancestral spirits. - Cutting them was prohibited as a way to honor ancestral spirits and protect the ecosystem.	
<i>Besale</i> ritual	- Involved offering gifts to the forest's spirits to express gratitude. - Reinforced sustainable resource use and involved children to teach conservation values.	
Ethical hunting practices	- Believed in animal guardian spirits. - Permission was sought before hunting; gratitude was expressed after success. - Bones/teeth were kept as tokens of respect.	
River rituals	- Rivers were used for purification ceremonies to cleanse evil energy. - Encouraged river cleanliness and responsible water management.	
Sacred times	- Periods of meditation and prayer were observed to respect nature. - Activities were paused to allow ecosystems to regenerate.	
Rituals to restore balance	- Disasters/illnesses were believed to result from ecological imbalances. - Rituals were performed to seek forgiveness and restore harmony with nature.	

“To us, there were trees that we treated as sacred; they must not be cut down. So, when we needed wood to build a hut, we looked for trees that were already old or nearly dead. You know, even before cutting, we always asked permission from the forest spirits to avoid any misfortune. That was our belief!” (E-A)

Elder A’s explanation reflects her community’s ecological understanding. Customary laws that prohibit the felling of certain trees help maintain the balance of the forest ecosystem. Furthermore, rituals performed to seek permission from the spirits guarding the forest illustrate that the Indigenous SAD regard the forest not only as a material resource but also as a spiritual entity deserving of respect. This tradition, as described by Elder A, embodies the belief that actions disrespecting nature could have adverse consequences for both humans and the environment. The Indigenous SAD also use specific methods for harvesting forest products such as rattan. One of the *Induk* shared her experience:

“Oh, we were very careful when we harvested rattan. Hmmm, how to explain it, hehehe ... (smiling). So, like this, we cut the rattan carefully; we didn’t pull out the roots because we wanted the rattan to grow back. We also didn’t take all of it; we left the younger stems to ensure the rattan didn’t run out. Something like that, very careful.” (I-C)

“Well, rattan had many functions; we used it to make baskets and ropes, which were important for our daily needs.” (I-C)

The methods employed, as explained by *Induk C*, demonstrate how the Indigenous SAD support the natural regeneration of rattan,

ensuring its long-term availability. This approach reflects their wisdom in utilizing natural resources without overexploitation. Their understanding of the rattan life cycle enables sustainable harvesting while maintaining ecosystem balance. Moreover, to sustain the wildlife population, the community implemented a rotational hunting system. One of the *Tumenggung* explained:

“Oh no, we didn’t hunt in one spot for a long time; that wasn’t good! Just so you know, we hunted from one place to another. This was our way to maintain the wildlife population. Once we had hunted in one place, we left it alone for a while so the animals could repopulate. After some time, we might return to hunt there again.” (T-C)

“I know, right, hahaha (laughing), if Orang Luar (lay people) found one good place to hunt, they took them all at once.” (T-C)

This approach reflects an effort to conserve wildlife populations by allowing specific areas time to recover. The rotational hunting system described by *Tumenggung C* not only supports ecosystem sustainability but also demonstrates a profound understanding of animal reproductive cycles. By avoiding overexploitation, the Indigenous SAD have been able to meet their food needs without disrupting the natural balance. This practice represents a simple yet effective form of the Indigenous SAD’s wisdom, passed down through generations, and serves as a component of community-based resource management. The interviews also revealed that land-clearing practices are carried out in ways that do not harm the environment. One of the *Induk* revealed:

"I felt sad to see the forest fire. Because for us, the forest was like a parent; the forest provided us with life. That's why we never burned the forest. When we needed to clear land for a temporary shelter, we only cleared the undergrowth and avoided cutting down large trees. This was our way; we just knew that when we moved to a new place, the land would eventually return to being a forest like it was before." (I-B)

Induk B's statement highlights the spiritual connection between the Indigenous SAD and the forest, where the forest is regarded not merely as a resource but as an integral part of life. This philosophy underpins their decision to avoid practices such as forest burning, which could cause permanent ecological damage. The practice of land clearing by removing only shrubs while leaving large trees intact reflects a high level of ecological awareness. By allowing the land to revert to forest once it is no longer in use, the community actively supports environmental sustainability. Furthermore, forest products are also utilized to create natural dyes for fabrics and crafts. Another *Induk* explained:

"Ooooh (an understanding expression), we knew nothing about chemicals. For us, everything was natural! Like we used leaves and tree bark to create natural dyes for fabrics and crafts. You know young guava leaves? Right ... that was what we used to make green dye, and for the red, we used mahogany bark. They were very beautiful colors!" (I-D)

Induk D's explanation highlights how this practice has become an integral part of local craft traditions passed down through generations. It reflects the community's skill and understanding of the potential offered by the natural resources around them. The dyeing techniques, which utilize natural materials such as young guava leaves for green and mahogany bark for red, demonstrate the community's creativity in optimally using forest resources without causing environmental harm. This practice not only supports cultural preservation but also embodies sustainable natural resource management, as exemplified by *Induk* D and her community. Moreover, the river plays a vital role in the lives of the Indigenous SAD. It is regarded as a source of life that must be kept clean. One of the elders shared:

"Well, for our side dish, sometimes we caught fish from the river. Fresh water to drink was also from the river. That's why we told our people to never throw chemicals into the river. When we bathed or washed, we only used natural materials, like soap made from Lerak fruit." (E-D)

Elder D's explanation illustrates the Indigenous SAD's awareness of the importance of the river as a source of clean water and a habitat for fish. This awareness is reflected in their efforts to avoid polluting the river with chemicals that could damage the ecosystem and threaten aquatic life. Elder D also emphasized the use of natural soap derived from *Lerak* fruit, demonstrating the Indigenous SAD's adoption of environmentally friendly local resources. Elder D's view of the river as a source of life reflects the Indigenous SAD's connection with nature, as the river is seen as an integral part of the ecosystem's balance. The belief that sharing with nature brings blessings is a guiding principle for the community. Vice *Tumenggung* stated:

"One very valuable thing that lived in the forest was that we got to gather honey and fruits. But again, remember, yes, hahaha

(laughing), we didn't take them all at once; we always left some for the animals in the forest. Our ancestors taught us that sharing with other creatures brought blessings. But if we were greedy and took everything, the forest would become angry and stop providing for us." (VT-D)

Vice *Tumenggung* D's statement reflects the community's spiritual perspective on the environment, where nature is treated as a living entity that must be respected. This belief fosters responsible behavior in sustainably utilizing natural resources. The view that the forest would "become angry" if exploited greedily serves as an effective mechanism for self-regulation, encouraging wise resource management. This principle demonstrates that local wisdom not only maintains ecosystem balance but also represents a form of conservation rooted in cultural values. This philosophy aligns with modern conservation principles, such as sustainability and biodiversity preservation, making it relevant for application in various environmental conservation efforts.

4.3 Social and ecological sustainability through tradition

The tradition of *melangun*, which involves relocating after the death of a family member, reflects a profound connection between humans, spirituality, and the environment. One of the *Tumenggung* explained:

"Hmmm ... (mumbling hesitantly), this was not easy to tell. But anyway, so, when a family member passed away, we moved to a new place; this was called 'melangun' We relocated to honor the spirit of the deceased and to give the forest time to recover from what we had taken. It was one of the hardest times, but we endured." (T-C)

"Oh, one more thing that many people didn't know. So, during melangun, we also explored new areas and learned about what we could eat (the resources) that were available there. This helped us understand more about the forest." (T-C)

Tumenggung C's explanation emphasizes that *melangun* is not only a form of respect for the spirits of deceased family members but also provides a space for emotional reflection for grieving families. Additionally, this tradition reflects the connection between spirituality and sustainability, as relocating helps reduce pressure on resources in the previous area and allows the forest time to regenerate. Moreover, the journey undertaken during *melangun* serves as a learning process about new areas and their natural resources, ultimately broadening the Indigenous SAD's understanding of the forest while enhancing its adaptability to environmental changes. In this sense, *melangun* also represents the Indigenous SAD's mobility as a dynamic adaptation strategy, enabling them to maintain ecological balance while forming deeper connections with new ecosystems. As *Tumenggung* C explained, this tradition exemplifies how social, spiritual, and ecological values intertwine to support the sustainability of both human life and the environment. In addressing illnesses, the community practices the tradition of *Besesandongon*, or self-isolation. One of the *Tumenggung* explained:

"Oh, let me tell you this. In our tradition, when someone was seriously ill, we did 'besesandingan.' Did you know that? (tried to ask), no? Alright ... so, the sick person stayed in a separate place alone, and the rest of the family provided food from a distance. This was to prevent the illness from spreading to others. We did this to make sure we understood the importance of maintaining health within the community." (T-D)

Tumenggung D's explanation highlights the Indigenous SAD's understanding of the importance of breaking the chain of disease transmission. Their practice of self-isolation, although simple, parallels modern principles of isolation in disease prevention. According to *Tumenggung D*, the tradition of *besesandingan* not only serves to protect the community from outbreaks but also instills important values such as mutual cooperation, disease prevention, and respect for individual healing processes. This practice fosters social harmony, ensuring that every individual feels supported even while undergoing isolation. *Tumenggung D's* account underscores that *besesandingan* is a form of local wisdom that reflects the Indigenous SAD's resilience in addressing health challenges without reliance on modern facilities. It often aligns with contemporary public health principles, demonstrating the effectiveness of traditional practices in maintaining community health and wellbeing. The marriage tradition, known as *bebalai*, serves as a moment to celebrate togetherness while also conveying environmental values. One of the elders explained:

"This tradition was my favorite, hahaha ... (laughing). When there was a wedding, we held a ceremony called 'bebalai.' Everybody celebrated it with dances and songs. But we never forgot to also teach about the importance of protecting the forest and working together as a community so that our lives could continue in harmony, just like the marriage! Hahaha ... (laughing)." (E-B)

Elder B emphasized that *bebalai* is not merely a ceremonial event but also serves as an important platform for imparting values of maintaining ecological balance and strengthening community solidarity. This tradition illustrates how the Indigenous SAD's culture naturally integrates ecological lessons into social life. As a form of informal education, *bebalai* ensures that younger generations understand the importance of cooperation and environmental preservation as the foundation for sustainable living. As Elder B explained, *bebalai* reflects a harmonious relationship between humans, culture, and nature, making it a tradition that not only reinforces community bonds but also supports environmental conservation. Since family is central to communal kinship, the Indigenous SAD ensure that they teach their children their Indigenous knowledge. Thus, early education plays a crucial role in preserving both traditions and ecosystems. One of the elders shared:

"The kids learned early about what they could and couldn't do. Like, they shouldn't break bird nests or take eggs from wild animals. This taught them to respect nature and all living things, so everything stayed in balance." (E-A)

Elder A's explanation reflects how education based on local wisdom instills conservation values from an early age. Prohibitions, such as not disturbing bird nests or collecting wild animal eggs, teach children the importance of maintaining ecosystem balance and protecting wildlife populations. Through this approach, children learn not only customary

rules but also the reasoning behind them, fostering strong ecological awareness. This education ensures that younger generations develop with a sense of responsibility toward the environment and respect for traditions that support nature conservation. As Elder A stated, this form of education helps preserve the human–environment relationship as part of the sustainability efforts rooted in tradition. The principle of interconnectedness among all living beings lies at the core of social and ecological sustainability. One of the vice *Tumenggung* stated:

"We believed that all living beings in the forest were interconnected. If one part was damaged, it would affect the others. That was why we lived by taking care of one another—humans, animals, and plants. This was what allowed us to continue living in the forest." (VT-C)

Vice *Tumenggung C's* statement reflects a holistic understanding of ecosystems, where each element supported the others in maintaining a natural balance. This principle of interconnectedness fosters responsible behaviors, such as preserving habitats, protecting biodiversity, and preventing the overexploitation of natural resources. This perspective also strengthens the harmonious relationship between humans and nature, with community members viewing themselves as an integral part of the ecosystem rather than its dominators. As Vice *Tumenggung C* expressed, this principle of interconnectedness is at the core of local wisdom, teaching collective responsibility that supports sustainable environmental conservation.

4.4 Spiritual connection with forest ecosystems

One form of expressing the spiritual connection with nature was through dance. One of the elders explained the *Tari Elang* (Eagle Dance):

"Of course, we did have, we had the Eagle Dance! This dance was unique, you know, because we performed it to call the spirit guardians of the forest. I enjoyed performing this dance. We named it the Eagle Dance because the moves were like [those of] a flying eagle, symbolizing strength and freedom. So cool, right? Hahaha ... (laughing) So actually, this dance taught us to live in harmony with nature and respect all living beings." (E-C)

The *Tari Elang* (Eagle Dance) reflects a profound spiritual connection between humans and nature, with the eagle symbolizing strength and freedom. This dance emphasizes the presence of forest guardian spirits as revered entities, reinforcing the belief that nature possesses a spiritual dimension that must be preserved. Through movements that mimic the eagle, the dance conveys respect for other living beings and demonstrates a deep understanding of the ecosystem.

The *Tari Elang* serves as an informal educational medium, teaching younger generations the values of sustainability and the importance of maintaining ecological balance. In addition to preserving tradition, the dance reinforces the cultural identity of a community that is deeply connected to nature. It delivers a conservation message through art, reminding us that environmental preservation is integral to living in harmony. As Elder C explained, the *Tari Elang* integrates art, spirituality, and ecology into a unified whole.

In addition to embedding ecological attachment in traditional ceremonies, the Indigenous SAD community also believe that certain trees hold spiritual significance and must not be cut down. One of the vice *Tumenggung* shared her perspective:

"In our custom, everybody knew that there were sacred trees that must not be cut down. These trees were believed to be the dwelling place of ancestral spirits. By protecting these trees, we also maintained our connection with our ancestors, and in return, we believed they would protect us." (VT-A)

The statement above represents the principle that protecting sacred trees is not only about preserving the forest but also about maintaining a spiritual connection with ancestors. These trees are regarded as symbols of protection and sustainability, reminding the community of their responsibility toward nature. Vice *Tumenggung* A's perspective illustrates that the belief in sacred trees serves as a natural conservation mechanism. This tradition, as recounted by Vice *Tumenggung* A, also acts as a means of passing down customary values to younger generations.

The prohibition against cutting sacred trees is not only a spiritual belief but also a conservation practice rooted in local wisdom. As Vice *Tumenggung* A explained, these trees not only offer spiritual protection to the community but also play a crucial role in sustaining the ecosystems that support their lives. The Indigenous SAD culture subsequently nurtured the *Besale* ritual, which represented the community's way of honoring the forest as a source of life. One of the elders explained:

"Oh well, yes, we did have another special ritual; we called it the 'Besale' ritual. So basically, we offered gifts to the forest spirits, usually food or other forest products. This was our way of expressing gratitude for the blessings the forest had given us. It had been passed down from generation to generation. We believed that by making these offerings, the forest's resources would continue to be abundant." (E-D).

It was apparent that *Besale* is more than just a ritual; it is a way for the community to remind themselves of their reciprocal relationship with the forest. Elder D emphasized that this ritual also establishes moral boundaries in the use of forest resources, ensuring that the community took no more than what was needed. The offerings made during the ritual symbolize respect for nature while serving as a reminder that the sustainability of the forest is key to collective wellbeing. As an informal educational tool, *Besale* is passed down to younger generations through direct involvement. Elder D explained that including children in the ritual helps them understand the importance of preserving the forest as a sacred space and a vital source of life. This tradition not only strengthens the community's connection with the forest but also fosters solidarity within the community. Another Indigenous SAD belief, relevant to protecting nature, was that the animals possess guardian spirits, which has influenced the community's hunting practices. One of the *Tumenggung* explained:

"We believed that every animal had a guardian spirit. Before hunting, we always asked for permission. If we were successful, we expressed our gratitude. Naaah (an expression), I bet you didn't know this yet, hahaha ... (laughing). We kept those animals' bones or teeth as a sign of respect. Interesting, right? Hahaha (laughing)." (T-A).

According to *Tumenggung* A, hunting is not merely about taking animals; it is a process that involves profound respect for living beings. He emphasized the importance of seeking permission from the animal's guardian spirit before hunting as a sign of respect and expressing gratitude after a successful hunt, reflecting the sacred relationship between humans and nature. *Tumenggung* A also explained that keeping bones or teeth as tokens of respect is part of tradition, which introduces ethical principles into hunting. This tradition teaches the community to hunt responsibly, without excess, and to take only what is truly needed. As *Tumenggung* A shared, it also serves as an informal educational tool for younger generations, instilling in them a respect for animals as integral parts of the life cycle rather than mere sources of food. The tradition establishes moral boundaries against exploitation, reinforcing spiritual values that align with modern conservation principles, such as respecting ecosystem balance and practicing sustainable resource use. As highlighted by *Tumenggung* A, this local belief is deeply rooted in the community's cultural identity, strengthening their connection to nature and their ancestral traditions. Moreover, the river also holds significant spiritual value for the community. One of the elders shared:

"You needed to know, for us, the river was a source of life. That's why, sometimes, we held ceremonies at the river to cleanse ourselves of negative energy. Behind this ritual, it was actually teaching us to keep the water clean because it was essential for our survival." (E-B)

Elder B's perspective emphasized that the river is regarded not only as a practical resource but also as a symbol of purification and healing. The ritual of self-cleansing performed in the river reflects the community's deep spiritual connection with water, reinforcing their motivation to maintain the river's cleanliness to ensure the sustainability of the ecosystem. The belief that water must remain pure to sustain life fosters collective awareness of the importance of responsible water management, preventing pollution. As Elder B explained, these rituals also serve as educational tools for younger generations, teaching them values of respect for water as a vital element of life. This tradition moreover ensures that awareness of the importance of water is passed down through generations, strengthening the community's cultural identity while supporting the sustainability of aquatic ecosystems. Additionally, local beliefs encompass specific times that were considered sacred. One of the elders explained:

"As an elder in my community, I reminded my people about certain times that we considered sacred, so we did not leave the forest. During these times, we usually meditated and prayed for the wellbeing of nature and our community. This helped us maintain balance within ourselves and with the environment." (E-C)

As explained by Elder C, meditation and prayers during sacred times serve as collective reminders to respect nature. By pausing certain activities, the community allows ecosystems to "rest," thereby supporting natural regeneration. These prohibitions also prevent the overexploitation of forests, as sacred times are dedicated to reflection rather than productivity. As Elder C noted, this tradition not only maintains the community's inner balance but also aids in the recovery of ecosystems. A noteworthy message pointing to the existence of Indigenous knowledge and awareness noted that the community understood that ecological imbalances could trigger disasters. One of the vice *Tumenggung* shared:

“This one I hoped would be an important message to all. Our tribe believed that illness and disasters occurred when nature was out of balance. So, we always tried to live in harmony with the forest. If something went wrong, we performed a ritual to apologize to nature, so that everything would be at peace again.” (VT-B)

Vice Tumenggung B's statement reflects the belief that human actions toward the environment have direct impacts on their lives. This awareness strengthens the collective responsibility to maintain ecosystem balance as a key to sustainable living. Rituals of seeking forgiveness from nature serve as collective reflections to acknowledge and rectify mistakes that may harm the ecosystem. These practices emphasize that restoring harmony with the environment is a crucial step in preventing further disasters and fostering both spiritual and ecological balance. The belief that disasters result from imbalance encourages the community to act responsibly in utilizing natural resources.

4.5 A framework for the indigenous SAD's wisdom and sustainability

Based on the aspects identified in the Indigenous SAD's wisdom (knowledge and practices), we developed a framework that integrates their wisdom with sustainability. This framework emphasizes how the Indigenous SAD's understanding of nature and its systems shape their sustainable practices and thus links food and environmental sustainability. Figure 2 was developed by mapping out the key elements of the Indigenous SAD's wisdom in relation to food and environmental sustainability. The process began by identifying the core components of the Indigenous SAD's traditional knowledge and practices, such as their connection to natural resources (forest, river, and wildlife), cultural practices and knowledge, and rituals and ethics. These components were placed in separate blocks to highlight their importance. The flow starts with natural resources, which form the foundation for the Indigenous SAD's way of life. It then moves to cultural knowledge and practices, which shape how the Indigenous SAD interact with nature.

Figure 2 incorporates the rituals and ethics that reinforce sustainable behaviors, and these practices directly lead to sustainable resource management. Next, Figure 2 links these sustainable practices to the outcome of balanced ecosystems and resource regeneration, showing how the Indigenous SAD's methods help preserve the environment. The central goal of sustainability in both the food and environmental domains is emphasized as the end result. Finally, the framework illustrates feedback at the top, which shows how sustainability reinforces and renews traditional knowledge and practices, ensuring the continued health of both the Indigenous SAD and the environment over time.

The framework for integrating the Indigenous SAD's wisdom with food and environmental sustainability began with natural resources, such as forests, rivers, and wildlife. These resources formed the foundation of the Indigenous SAD's traditional knowledge and practices, offering essential materials for food, medicine, and cultural rituals. The Indigenous SAD rely on these resources, recognizing their importance in maintaining both their cultural practices and the health of the environment. This relationship with nature is governed by cultural practices and knowledge, which encompass the beliefs, values, and methods passed down through generations. The rituals and ethics embedded within these cultural practices—such as the Eagle Dance and *Besale* rituals—play a role in strengthening the Indigenous SAD's respect for nature.

Moreover, the practical application of these cultural beliefs are evident in the sustainable practices of the Indigenous SAD, including hunting, foraging, and resource management. These practices are integral not only to the Indigenous SAD's survival but also to maintaining environmental health. These sustainable practices foster balanced ecosystems and resource regeneration. For example, rotational hunting practices and careful forest management contribute to the conservation of biodiversity and the regeneration of ecosystems. At the center of the framework is achieving food and environmental sustainability. The final component of the framework is feedback, which reinforces the roles of sustainability and traditional knowledge. As the Indigenous SAD practice sustainability, they receive the benefits of a thriving environment, which in turn strengthens their cultural practices.

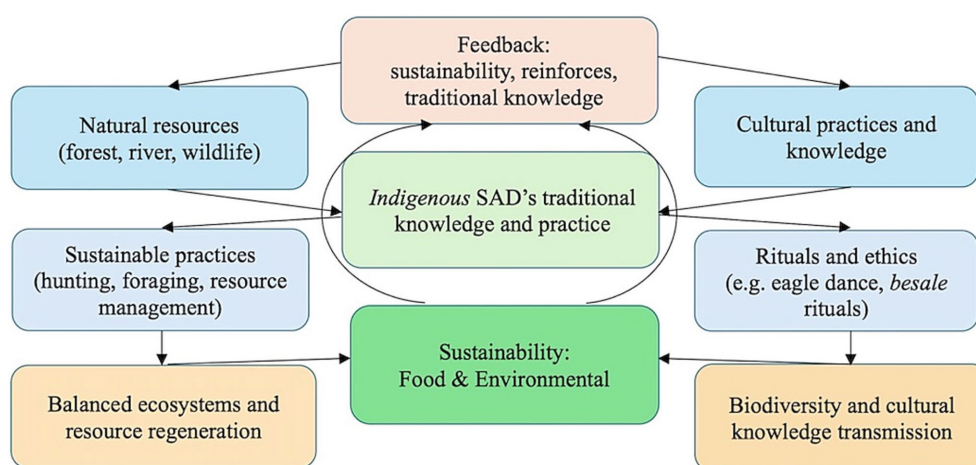


FIGURE 2

Framework for integrating the Indigenous SAD's knowledge and practices with sustainability.

5 Discussion

This study underscores the importance of the Indigenous SAD wisdom in promoting food and environmental sustainability. These practices align with ecological theories, global regulations, and prior research findings, demonstrating how Indigenous knowledge systems offer effective models for sustainable resource management. One significant aspect of the knowledge held by the Indigenous SAD pertains to their hunting practices, which involve tools such as *kujur* (wooden spears) and blowpipes equipped with natural poisons from the sap of the *ipuh* tree. These methods exemplify a low-impact approach to hunting, thus minimizing disruption to ecosystems. This practice supports Berkes's (2017) theory that Indigenous ecological knowledge is essential for sustainable resource management. Comparable findings by Colchester et al. (2004) indicate that traditional hunting methods employed by Southeast Asian Indigenous communities contribute to the maintenance of ecological balance. The use of biodegradable tools by the Indigenous SAD contributes to the preservation of animal populations and represents a significant departure from modern hunting technologies, which often cause greater ecological harm. These findings echo those documented by Sager (2008), who explored the customs and cosmological beliefs of the Orang Rimba—which refers to the Indigenous SAD community—in the Bukit Dua Belas National Park, emphasizing the centrality of spiritual practices in shaping environmental interactions. This is consistent with First Nations' approaches to natural resources that emphasize holistic stewardship and ecological reciprocity, as outlined by Lickers (1994).

Building on their sustainable hunting methods, the Indigenous SAD's foraging practices demonstrate selective harvesting techniques that promote resource regeneration. The meticulous collection of forest fruits, such as wild durian and jernang resin, exemplifies an approach that aligns with Leopold's (2014) land ethic, which advocated for responsible environmental stewardship. Additionally, their ability to time harvests, such as collecting mushrooms after rainfall, demonstrates a profound understanding of ecological cycles. These findings align with those of Klein et al. (2007), who emphasized the importance of sustainable harvesting in preserving ecosystem health. This evidence also supports the conclusion of Sheil et al. (2002) that Indigenous practices often surpass contemporary management strategies in promoting forest regeneration.

In addition to foraging, the food processing techniques employed by the Indigenous SAD illustrate their adaptability and ecological knowledge. For example, their method of detoxifying gadung tubers through prolonged immersion in water exemplifies an understanding of biochemical processes. This finding aligns with the observations of Gadgil et al. (1993) regarding the intergenerational transmission of ecological knowledge. Additionally, sustainable honey harvesting practices that use smoke to safely deter bees exemplify the principles of sustainable apiculture articulated by Klein et al. (2007). These methods emphasize the importance of pollinator protection, further highlighting their role in supporting biodiversity.

In addition to their food-related practices, the Indigenous SAD implement resource management strategies that prioritize sustainability. A notable example is their method of harvesting rattan while preserving the roots to promote regeneration. This approach exemplifies Ostrom's (1990) principles of common-pool resource management, wherein shared norms help prevent overexploitation.

Similarly, their rotational hunting methods demonstrate an understanding of ecological principles, including the carrying capacity and species reproduction rates. These findings align with Folke et al.'s (2005) findings that mobility and adaptability enhance ecological resilience. The Indigenous SAD's tradition of *melangun*—a practice of relocating after a death to facilitate forest recovery—supports Walker et al.'s (2020) assertion that Indigenous land use strategies often provide critical recovery time for ecosystems. Moreover, the Indigenous SAD's knowledge aligns with contemporary One Health perspectives that advocate for integrated human, animal, and environmental health strategies (Pollowitz et al., 2024; Sudlovenick et al., 2024; Wingett et al., 2025).

The philosophy of interconnectedness espoused by the Indigenous SAD is exemplified by their practice of leaving portions of honey and fruit for wildlife, underscoring the vital role that animals play in sustaining ecological balance. This approach embodies the ecosystem-based methods advocated by the Convention on Biological Diversity (Bragdon et al., 2012), which aligns human needs with ecological integrity. The use of natural products such as lerak fruit for soap, along with a commitment to keeping rivers clean, aligns with the principles of Integrated Water Resources Management as outlined by UNESCO (van der Zaag and Savenije, 2004), which emphasizes the importance of preserving aquatic ecosystems. These findings highlight the importance of Indigenous SAD practices in the context of global ecological theories, policies, and sustainability goals. As noted by Gadgil et al. (2021), integrating Indigenous knowledge into global policy frameworks is crucial for effective biodiversity conservation. This study underscores the potential of Indigenous SAD practices to inform sustainable development initiatives, particularly in achieving SDG 12 (Responsible Consumption and Production) and SDG 15 (Life on Land). By partnering with Indigenous communities, conservation efforts can become more inclusive and effective, utilizing traditional knowledge to address pressing global environmental challenges.

While this study adopts an Indigenous research methodology, including participatory frameworks and OCAP principles, it also contributes to a broader assessment of existing Indigenous research methodologies. As highlighted in the work of Kovach (2017) and Wilson (2020), Indigenous methodologies challenge extractive research paradigms by prioritizing relational accountability, reciprocity, and community-defined benefits. However, such approaches remain underrepresented in mainstream environmental research. The integration of oral histories, participatory codesign, and cultural protocol adherence in this study exemplifies the transformative potential of Indigenous methodologies in both ethical engagement and knowledge coproduction. This approach aligns with the global movement to decolonize research practices and reaffirm Indigenous data sovereignty, as advocated by Chilisa (2019) and Kukutai and Taylor (2016).

6 Conclusion and recommendations

This study highlighted the contributions of the Indigenous SAD's traditional ecological knowledge and practices with respect to food sustainability and environmental conservation. These practices, such as selective harvesting, sustainable hunting, resource regeneration, and spiritual reverence for nature, are aligned with key ecological

theories and global conservation principles and demonstrate that Indigenous knowledge could address contemporary environmental challenges by fostering biodiversity, maintaining ecological balance, and promoting responsible resource management. The emphasis on interconnectedness with nature and sustainable living strategies provides insights into achieving global sustainability goals, particularly in terms of food and environmental conservation. Integrating such Indigenous wisdom into modern conservation policies could yield culturally inclusive and ecologically effective solutions for global challenges.

Integrating traditional ecological practices into formal conservation frameworks can significantly improve biodiversity conservation and sustainable resource management. Policy-makers should collaborate with Indigenous communities to develop inclusive policies that honor and enhance their contributions, ensuring that these practices are preserved and adapted to meet contemporary environmental challenges. Future research should explore the broader implications of the Indigenous SAD practices in tackling global environmental issues. Comparative studies with other Indigenous communities could reveal shared principles and strategies that can be scaled and adapted to various ecological and cultural contexts. Such research would validate the relevance of Indigenous wisdom and create opportunities to connect traditional knowledge with modern scientific methods, fostering innovative and sustainable solutions for global conservation efforts.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the dataset were managed in compliance with ethical research guidelines. Requests to access these datasets should be directed to sadarginting_s@cmu.ac.th.

Ethics statement

The studies involving humans were approved by Indonesia's National Research and Innovation Agency (BRIN). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SG: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration,

Writing – original draft, Writing – review & editing. AW: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. SO: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. SH: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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