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RESEARCH ARTICLE

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Transformation and endurance of Indigenous hunting: Kadazandusun-Murut bearded pig hunting practices amidst oil palm expansion and urbanization in Sabah, Malaysia

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Abstract

1. Land-use change and political–economic shifts have shaped hunting patterns globally, even as traditional hunting practices endure across many local socio-cultural contexts. The widespread expansion of oil palm cultivation, and associated urbanization, alters land-use patterns, ecological processes, economic relationships, access to land and social practices.
2. In particular, we focus on the socio-ecological dynamics between Kadazandusun-Murut (KDM) hunters in Sabah, Malaysian Borneo, and bearded pigs (*Sus barbatus*; Malay: 'babi hutan'), the favoured game animal for non-Muslim communities throughout much of Borneo. We conducted 38 semi-structured interviews spanning over 50 hr with bearded pig hunters, asking them about contemporary hunting practices and motivations, changes in hunting practices, changes in pig behaviour, and patterns of animal protein consumption in village and urban contexts.
3. Amidst widespread land-use change, primarily driven by oil palm expansion, respondents reported substantially different characteristics of hunting in oil palm plantations as compared to hunting in forests. Additionally, 17 of 38 hunters—including 71% (10/14) of hunters who started hunting before 1985, compared to 26% (6/23) of hunters who started hunting in 1985 or later—mentioned that bearded pigs are behaving in a more skittish or fearful way as compared to the past. Our respondents also reported reductions in hunting frequency and wild meat consumption in urban contexts as compared to rural contexts.
4. However, despite these substantial changes in hunting and dietary practices, numerous KDM hunting motivations, hunting techniques and socio-cultural traditions have endured over the last several decades. For some, bearded pig meat remains deeply tied to food provision, gifting and sharing customs, and cultural components of celebrations and feasts.

5. Oil palm has cultivated new hunting practices that differ from those in forests, and has potentially contributed to altered bearded pig behaviour due to increased hunting accessibility. Together, oil palm and urbanization are helping reshape the KDM-bearded pig socio-ecological system. In light of these reshaped connections, we recommend location-specific management approaches that ensure fair access to the dietary and social benefits of bearded pig hunting while preserving the critical conservation needs of bearded pig populations and habitat. These twin goals are particularly urgent given the confirmed outbreak of African Swine Fever (ASF), and mass deaths of domestic pigs and wild bearded pigs, in Sabah and Kalimantan in 2021.

KEYWORDS

African Swine Fever, Borneo, coupled human and natural systems, environmental governance, land-use change, socio-ecological systems, Southeast Asia, wildlife management

1 | INTRODUCTION

Hunting has been called 'the master behaviour pattern of the human species … which puts motion and direction into the diagram of [hu] man's morphology, technology, social organization, and ecological relations …' (Laughlin, 1968). In addition to the provision of meat, a typical hunting event includes, among other behaviours, searching for prey, pursuing animals, killing and butchering one or more animals, transporting carcasses, distributing meat among households or markets and communicating ecological information throughout and following the hunt (Laughlin, 1968; Puri, 2005). Correspondingly, a great number of physical, cultural, social and ecological dynamics are linked to hunting practices: hunting is, in short, one of the most fundamental and enduring of human–wildlife relationships.

Land-use change and hunting are intimately linked. For example, land conversion increases access to wildlife habitats and often leads to dramatic and unsustainable levels of hunting (e.g. Abernethy et al., 2013; Harrison et al., 2016; Parry et al., 2007). Furthermore, land conversion has been shown to influence hunting practices and techniques in a variety of socio-cultural contexts (Luskin et al., 2014; Wightman et al., 2002). The many and varied modes through which land-use changes interact with hunting practices call for greater understanding of the links between socio-ecological systems, social practices, food security and the sustainability of wildlife populations (Bassett, 2005; Brashares et al., 2014). Drawing on a case study of these integrated dynamics, we investigate the ways that oil palm expansion, urbanization and ancillary socio-cultural factors have been tied to the transformation and endurance of bearded pig hunting practices in Sabah, Malaysia.

1.1 | Historical and contemporary bearded pig hunting practices in Borneo and Sabah

The bearded pig (*Sus barbatus*, Bahasa Melayu—'*babi hutan*': 'forest pig') is a large, nomadic Suid species native to Sundaland and woven into the socio-ecological fabric of Borneo (Luskin & Ke, 2018; Puri, 2005). Bearded pig hunting is a deeply embedded social practice in many Indigenous communities in Borneo, who have hunted and consumed bearded pigs for over 40,000 years (Harrisson et al., 1961; Medway, 1964). For example, for the Penan Benalui in East Kalimantan, hunting is the most regularly occurring economic activity and a central organizing activity in Penan society (Puri, 2005). Some traditional hunting techniques are also tied to nomadic movements of bearded pigs (e.g. Banks, 1949), which are thought to periodically move long distances of up to 650 km in large herds of up to 300 individuals (Caldecott et al., 1993; Davies & Payne, 1982; Pfeffer, 1959). Bearded pig meat has been shown to account for 54%–97% of wild meat by weight in Indigenous Bornean societies (Bennett et al., 2000; Chin, 2001; Puri, 2005), for whom wild meat can contribute to as much as 36% of meals (Bennett et al., 2000). Thus, the bearded pig is the most heavily consumed terrestrial game animal for Indigenous, non-Muslim communities throughout Borneo, and is also widely considered the favourite type of wild meat among many of these communities (Bennett et al., 2000; Chin, 2001; Janowski, 2014; Puri, 2005).

Bearded pig hunting also holds significant implications for recreation, gift-giving and social practices in many Indigenous Bornean communities (Harrisson, 1965; Janowski, 2014; Wadley & Colfer, 2004). More broadly within Malaysia, pigs and pig hunting are situated at intersections of religion, ethnic identity and geography. In Malaysia, a multicultural society politically controlled by ethnic Malays, one of the many socio-religious delineations between Malay Muslim elites and other ethno-religious groups is the consumption of pig meat: for religious reasons, many Malay Muslims find pigs and pork highly objectionable—to the point that '*babi*' ('pig') is an insult (Yusof, 2012). In contrast, other groups, including ethnic Chinese minorities, consume pork in large quantities (Neo, 2011). The prominence of religious food practices has a dramatic influence on patterns of pork consumption in Malaysia (Chua, 2012), to the extent that a 'pig line' has even been described in Sarawak, delineating predominantly Muslim coastal fishing communities from primarily

non-Muslim inland communities who are nutritionally dependent on wild pig meat (Bolton et al., 1972). Similarly, ethno-religious dynamics shape hunting practices and influence which species are targeted for hunting in Indonesian Borneo (Wadley et al., 1997).

Pig hunting practices take place within an environmental context of widespread deforestation and agricultural expansion (Gaveau et al., 2014; Wong et al., 2012). Luskin and Ke (2019) estimated significant (20% or more) habitat loss and range reduction from 1990 to 2010 in each of the three bearded pig range locations: Peninsular Malaysia, Sumatra and Borneo. This decline was driven by agriculture-related habitat fragmentation (primarily due to oil palm and rubber plantations), leading to the recent re-listing of the bearded pig as a Vulnerable species in the International Union for Conservation of Nature and Natural Resources Red List (Luskin, Ke, et al., 2017). In addition to contributing to habitat loss, oil palm plantations have reshaped bearded pig ecology by reducing the area available for some behaviours (e.g. limited wallowing and nesting sites in plantations), altering demographics (e.g. increasing the proportion of young pigs in plantations) and changing activity patterns (e.g. shifting pigs to nocturnal activity patterns in plantations) (Davison et al., 2019; Love et al., 2018). Bearded pigs also receive food subsidies from crop-raiding within oil palm plantations (Davison et al., 2019; Love et al., 2018), and it has been hypothesized that this behaviour could potentially increase wild pig populations near oil palm (Davison et al., 2019; Love et al., 2018; Luskin, Brashares, et al., 2017). These findings raise questions about how bearded pig responses to forest-oil palm mosaics might affect hunting practices, and about how bearded pig hunting should be appropriately managed for long-term bearded pig conservation and socio-ecological sustainability.

Across the bearded pig range, pig hunting management is regulated by a heterogeneous matrix of policies. Hunting of the species is permitted in some form across bearded pig range countries (Indonesia, Malaysia and Brunei), with restrictions varying by jurisdiction and including measures such as hunting permits, no-hunting protected areas and native hunting clauses (Brunei Wildlife Protection Act 1984, Act of the Republic of Indonesia No. 5 of 1990 concerning Conservation of Living Resources and their Ecosystems, 1990, Laws of Sarawak, Wild Life Protection Ordinance, 1998; Wildlife Conservation Enactment 1997). Law enforcement capacity also varies by region (Bennett et al., 2000; Lintangah et al., 2015; Luskin et al., 2014).

In Sabah, Malaysia, it is legal to hunt bearded pigs and sell the meat with appropriate licenses from the Sabah Wildlife Department (Wildlife Conservation Enactment 1997). A sport hunting licence for bearded pig costs 5.00 MYR (~1.22 USD) per animal and a commercial hunting licence for bearded pig costs 50.00 MYR (~12.17 USD) per animal (Wildlife Conservation Enactment 1997).

Hunting of bearded pigs in Sabah is widespread in many rural areas, and bearded pig meat remains an important food resource for many communities (Bennett et al., 2000; Mojiol et al., 2013). However, a recent African Swine Fever (ASF) outbreak in Sabah has raised concerns for bearded pig populations as well as for local communities (Chan, 2021; The Star, 2021). First reported at the end of 2020, ASF has spread rapidly throughout numerous forests and districts in Sabah over the first half of 2021 (S. Nathan, pers. comm.). ASF is a deadly virus with case fatalities in domestic and wild pigs ranging from 47.7% to 100% (FAO, 2021a; Liu et al., 2020).

To mitigate the spread of ASF and due to movement control orders related to the COVID-19 pandemic, the government froze hunting licences in Sabah in early 2021 (Chan, 2021; The Borneo Post, 2021; The Star, 2021). In mid-2021, there were also reports of confirmed ASF cases as well as mass bearded pig deaths in Kalimantan (Berau Post, 2021; Fadil, 2021), indicating possible spread of ASF through wild bearded pig populations beyond Sabah.

1.2 | Economic, environmental and social processes of oil palm expansion in Sabah

Sabah has been on the frontlines of the oil palm boom since the late 20th century. This transformative process is noteworthy for its deep roots in globalized commodity chains, through which oil palm became highly valued as a 'global flex crop' useful for food, fuel and personal care (Alonso-Fradejas et al., 2016). By the 1960s, Borneo had been identified as a major resource frontier, providing more tropical timber than anywhere else in the world by the late 1970s (Brookfield et al., 1995). With timber extraction helping pave the way for oil palm expansion, Malaysia emerged as the global leader in palm oil production in the 1970s (FAO, 2021b). By the early 1980s, oil palm had become Sabah's most important cash crop, fuelled by high profitability and the diversity of commercial applications for palm oil (Bernard & Bissonnette, 2011). Oil palm plantation area in Sabah reached over 1.7 million ha (6,867 sq. miles) by 2015; 68% of this total area was converted to oil palm within 5 years of forest clearance (Gaveau, Sheil, et al., 2016). As of 2015, roughly 24% of Sabah's total land area was covered by oil palm or pulpwood plantations (Gaveau, Sheil, et al., 2016).

These large-scale economic and land-use changes resulted in profound shifts in socio-ecological relationships in Sabah. In significant part, Sabah became a particular manifestation of the 'global land grab' in which large tracts of land were allocated to a small number of business, bureaucratic and political elites (Cramb & Curry, 2012). Indeed, some have argued that this socio-environmental shift represents an extension of colonial legacies of territorialization, with large plantation corporations taking a capitalist role analogous to their imperialist land-control forbearers and shaping labour relations and livelihood options across the state (Bernard & Bissonnette, 2011; Cooke, 2012). While oil palm smallholdings became popular and often profitable options for some Sabahans with access to land (Cooke, 2012), most labour and management in the vast stretches of industrial oil palm plantations began coming from outside of Sabah. For example, by the late 1990s, 95% of workers on Federal Land Development Authority (FELDA) plantations in Sabah were migrants from the Philippines

or Indonesia (Bernard & Bissonnette, 2011). As a result, this migrant labour force, consisting of both legal and illegal workers, has become a mainstay of Sabah's plantation economy (Kelly, 2011). For their part, Sabahans may take administrative (or occasionally labourer) positions within large oil palm companies, own their own oil palm smallholdings, or move to urban areas for relatively well-paying jobs in manufacturing and retail. For those Sabahans remaining in rural parts of the state, disputes over land allocation and ownership have reduced access to croplands and forests in some areas, weakening traditional forms of food security and restricting accessibility to non-timber forest resources (Bernard & Bissonnette, 2011). Due in large part to the vast areas already gazetted for timber production and oil palm plantations, new land for oil palm 'either has to encroach on claimed but untitled lands on which customary rights have been established or excised from existing government forest reserves' (Cooke, 2012).

1.3 | Oil palm expansion, urbanization and bearded pig hunting among Kadazandusun-Murut (KDM) hunters in Sabah

Despite the historical and contemporary prominence of bearded pig hunting and dietary relationships, there has been little published research on these practices and how they have been reshaped by the socio-economic and environmental changes brought about by oil palm expansion. Case studies and syntheses, both regional and global, are needed to elucidate how relationships between human societies and natural resources change in response to factors such as land-use change and political–economic forces (Lambin & Meyfroidt, 2010). In this paper, we argue that the socio-ecological processes of oil palm expansion and urbanization in Sabah have profoundly shaped—and continue to shape—hunting practices within the influential Kadazandusun-Murut ethnic group (or 'KDM', the common shorthand for this community in Sabah). The KDM make up roughly a third of the *Bumiputera* population (literally translated to 'sons of the land', used in Malaysia to refer to Malays and Indigenous ethnic minority groups) within the state of Sabah, and over 20% of the total population of Sabah (Malaysia Department of Statistics, 2011). Within Sabah, the KDM peoples are considered among the *Orang Asal*, or Indigenous Peoples of Malaysia. In this study, we investigate the particular ways that KDM-bearded pig hunting practices have been preserved or changed in the face of the environmental, economic and social changes that have come with oil palm expansion and urbanization. Specifically, we interviewed KDM hunters in Sandakan District, Sabah, to infer persistence and change in their hunting practices, perceptions of bearded pig behaviour, meat and fish consumption patterns, hunting motivations, and hunting techniques. We discuss ways our findings shed light on the relationships between oil palm expansion, urbanization and hunting, and we call for biocultural conservation that encompasses KDM social practices as well as long-term management of bearded pig populations.

2 | METHODS

2.1 | Study area

We conducted our study in Sandakan District (5.840415, 118.116757), located along the eastern coast of Sabah, Malaysian Borneo (Figure 1). Sandakan is the third most populous district in Sabah, with a population of 396,290 in the 2010 census (Malaysia Department of Statistics, 2015). Between 2000 and 2010, the population of the district grew by 13.6% (Malaysia Department of Statistics, 2015). Most land area in Sandakan district is covered by industrial plantation agriculture (Gaveau et al., 2014). The Sandakan economy is also supported by numerous factories and industrial uses, including oil terminals, oil refineries, glue factories, a shipyard

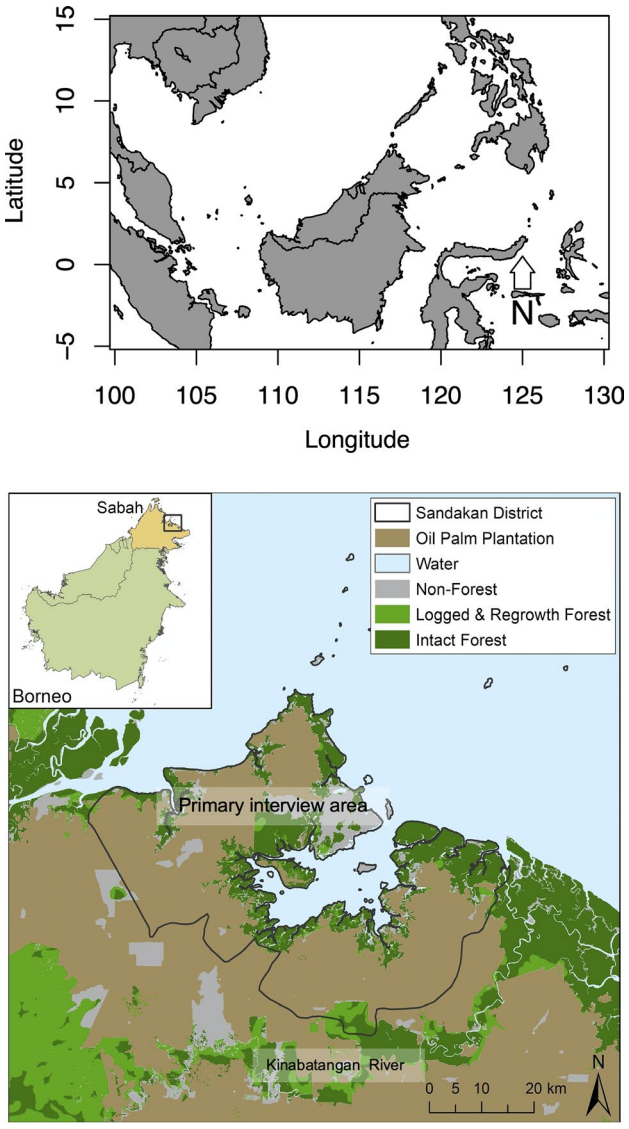

FIGURE 1 Situated within Southeast Asia (top), the study area was Sandakan District, Sabah, Malaysian Borneo (bottom). Top map created with package 'mapdata' (Becker & Wilks, 2018). Bottom map created using land cover data from Gaveau, Salim et al. (2016) and with ArcMap version 10.7.1 (Esri Inc, 2019)

and wood-based factories (Sabah State Government, 2014). Of the Malaysian citizen population of Sandakan (constituting 63% of the total population), 71% identify as *Bumiputera* (Malay, Kadazandusun, Bajau, Murut and other Bumiputera), 25% are of Chinese descent, 0.4% are of Indian descent and 3.5% are from additional racial-ethnic groups (Malaysia Department of Statistics, 2015).

2.2 | Data collection

We conducted 38 in-depth, semi-structured interviews with Kadazandusun-Murut (KDM) bearded pig hunters in 2019 in Sandakan District (Figure 1). Our interview protocol was approved by the Committee for Protection of Human Subjects at the University of California, Berkeley (Protocol number: 2019-04-12096), by the Sabah Biodiversity Council (Ref. No. JKM/MBS.1000-2/2 JLD.9 (59)), and by the Sandakan Municipal Council (Ruj.MPS100-48/001/0000/035). All hunters interviewed were men. Although women in some Bornean communities play significant roles in the various cultural practices associated with bearded pig consumption,[1] we did not encounter any women engaged in hunting over the course of our study. More broadly, hunting is typically associated with men in Indigenous Bornean societies (Alexander & Alexander, 1994; Thambiah, 1997). We defined a 'hunter' as someone who had hunted bearded pigs twice per year or more, on average, for a span of at least 5 years. A hunter did not need to be hunting regularly at the time of the interview to be included in our study. We identified hunters through our existing social and professional networks, and we relied on referral ('snowball') sampling, by which respondents connected us with other hunters. While this strategy did not provide us with a representative pool of the KDM hunting community in Sandakan District, it promoted trust and helped identify a set of highly knowledgeable respondents (e.g. Luskin et al., 2014). When potential respondents were in a village (*kampung*) setting, we sought and received permission from the village chief before proceeding with interviews. Before conducting an interview, we asked each participant for his verbal consent to participate in the research. We asked for verbal consent to accommodate respondents who may have felt uncomfortable reading or signing a written consent form. To protect the privacy of respondents, we did not record their names or any audio.

Two (J.B., V.T.J.) or three (D.J.K., J.B. and V.T.J.) authors conducted each interview, primarily in Bahasa Melayu (supplemented only occasionally with English if respondents were comfortable and chose to speak in English). Both primary interviewers (J.B. and V.T.J.) spoke fluent Bahasa Melayu, and one of the primary interviewers (V.T.J.) is a local Sabahan. Each interview lasted from 0.5 to 2.5 hr, and took place in a location chosen by the respondent. Respondents were normally interviewed individually, but occasionally social norms and relationships led to respondents being more comfortable with an interview in a small group (i.e. 2–3 individuals). Our survey consisted of basic demographic information (e.g. age group, home village/city, education level, work information) and questions about their hunting practices (see Supporting Information for interview guide in English and Bahasa Melayu). We asked hunters to compare their hunting practices in oil palm plantations and forest. We also asked hunters about perceived changes in: their bearded pig hunting practices, the influence of their jobs on hunting, their hunting locations and bearded pig ecology. Respondents were also asked about their hunting motivations, animal protein consumption patterns in village and urban contexts, hunting techniques, hunting narratives and hunting success rates. Most of the questions asked were open-ended, but we also asked closed questions to gather readily quantifiable information about certain categories. To avoid asking for sensitive information and making our respondents uncomfortable, we did not ask whether they had obtained the appropriate licences for hunting or sale of bearded pig meat. We did not compensate respondents for participating in the study.

To quantify meat and fish consumption patterns, we asked respondents how many times in the previous week they had eaten: bearded pig meat, deer meat, any other kind of wild meat, wild fish from rivers, wild fish from the sea, and domestic chicken, domestic pig, or other domestic meat. We asked respondents to share their consumption patterns for both village (*kampung*) and city (*bandar*) settings, as many respondents had spent significant time living in each setting or regularly moved back and forth between each context. To quantify hunting success, we asked respondents how many hunting trips for bearded pig, on average, were successful out of four attempts.

To quantify bearded pig hunting motivations, we asked hunters to rank common motivations from several categories: food provision (*makan*), sale for money (*jual*), recreation (*hobi*), pest control (*kawalan perosak*), gift (*hadiah*) or other (*lain-lain*). To quantify the frequency with which different hunters used different techniques, we asked respondents to indicate yes (*ya*) or no (*tidak*) to whether they had ever used the following common hunting strategies: dog and spear (*anjing dan tombak*), spear only (*tombak sahaja*), dogs and gun (*anjing dan senapang*), gun on foot (*senapang sahaja [kaki]*), drive hunt with gun (*senapang sahaja [kereta]*), snare (*jerat*), trap (*perangkap*), homemade bomb (*bom babi*) and other (*lain*).

2.3 | Respondent characteristics

Hunter ages ranged from 26 to 72 years, with a mean age of 47 years. Most hunters had attended school until Form 1–5 (corresponding to 13–17 years of age), a few had received their Sijil Pelajaran Malaysia (Malaysia Certificate of Education, equivalent to a US high school degree) and a small minority of respondents had attended university or institute programmes. Respondents worked in a variety of fields, including the oil palm industry (smallholder and industrial), police and government service, the clergy, semi-professional hunting, forestry, farming, rideshare driving and various forms of self-employment. Twenty-seven out of 36 respondents (75%) said they had worked in oil palm agriculture at some point, whether as smallholders or in industrial oil palm plantation roles.

2.4 | Data analysis

To investigate whether hunting practices have changed due to the expansion of oil palm plantations in Sandakan District, we compared hunting techniques used by hunters who started hunting earlier and later in the process of oil palm expansion in Sabah. We calculated the approximate year each hunter began hunting, based on their current age and the age they began hunting. We separated hunters into two categories: those who began hunting before 1985, and those who began in 1985 or later. We chose 1985 for this analysis, as extensive oil palm expansion in the Sandakan district occurred throughout the 1970s, resulting in an oil palm-dominated landscape by the late 1970s and 1980s (Dayang Norwana et al., 2011; Gaveau, Sheil, et al., 2016). To test for differences in hunting techniques between the two categories of hunters, we conducted a Fisher's exact test in R version 3.6.0 (R Core Team, 2019).

Qualitative data were analysed via inductive content analysis (Elo & Kyngäs, 2008), in which we started with specific observations of individual hunters and moved to a more general framework of contemporary KDM hunting practices among our respondent pool. We present our findings as a sequence of themes that emerged from the interviews (e.g. Dhee et al., 2019). We focused our analysis on (a) endurance and transformation of KDM pig hunting and dietary practices; and (b) the specific influences of oil palm expansion and urbanization on the persistence and change in these practices. We present interview excerpts as English translations, with the original Bahasa Melayu quote sometimes included to present respondent insights in their own language and expression.

3 | RESULTS

3.1 | Differing hunting practices in forest and oil palm plantations

In response to an open-ended question about whether hunting in the forest is different from hunting in oil palm, hunters reported several distinct characteristics of hunting in each environment (Table 1). Most prevalent was the perception that hunting in oil palm plantations was easier overall than hunting in forests, for example, because it was generally less tiring than walking in a forest, easier to see or find pigs or more predictable in terms of knowing exact foraging locations preferred by pigs. Hunting in forests was characterized by a number of hunters as being harder overall than hunting in plantations, and involved walking on foot (often for longer distances). For example, Respondent 14 contrasted the two styles of hunting this way: 'In the plantation you know the pig will come eventually—it's only a matter of time', whereas in the forest 'it's not as certain even if you hunt all day long—because you will need to walk and only if you cross paths with it will you get it—if you do, you do'.

Additionally, five respondents noted a difference between the taste of the meat from pigs in oil palm plantations as compared to forest. Three hunters specifically expressed a preference for the taste of pig meat from forest. Respondent 20 commented, 'The pig from the forest is much tastier, it's more fit. If the pig eats oil palm its fat isn't as sweet. It's very rare to meet a pig that's never eaten oil palm'.

3.2 | Perceived changes in pig ecology over time

In response to an open-ended question about whether they had noticed any changes in bearded pig behaviour since they had started hunting, more than half of all respondents (20/38) noted some type of pig behaviour change over time (Box 1). In particular, 17 hunters replied that they noticed that pig behaviour had become more skittish, wild or fearful over the years. Among hunters who had started hunting before 1985, 71% (10/14) noted this increased flight response, whereas only 26% (6/23) of hunters who started hunting after 1985 mentioned this behavioural change. Additionally, five hunters noted other pig behaviours (e.g. activity patterns) that they perceived to have changed over time. For example, one hunter hypothesized that pigs change their behaviour in response to the schedule of workers in the plantation, suggesting that the pigs came into the plantation after workers had gone home for the day.

Some hunters reported seeing bearded pig eruptions of scores or hundreds of individuals, although these observations were typically made by older hunters. Several hunters in our study described these pig eruptions with awe, fear, excitement or shock. For example, Respondent 5 said: 'I was sitting in a tree when a huge herd of pigs came by. I was so shocked that I didn't even shoot any. I just sat there counting them'. Respondent 15 commented, 'There are so many pigs that all you can do is just stand and stare until they run away'. A few hunters acknowledged that large pig aggregations occurred, but

TABLE 1 Salient themes of hunting in forest and oil palm plantations mentioned by hunters in response to an open-ended question about the difference between hunting in the two habitat types

Characteristics of hunting in forest	No. hunters	Characteristics of hunting in oil palm plantations	No. hunters
Harder overall (e.g. more tiring, more variable)	8	Easier overall (e.g. less tiring, more predictable)	9
Hunting on foot	6	More waiting for pigs	5
Walking farther distances	5	Easier to find/see pigs	4
Easier to get more pigs	2	Predictable places pigs come to forage	3
		Hunting with a car	2

BOX 1 Selected English translations (from Bahasa Melayu [Malay]) of quotations from respondents who perceived changes in bearded pig behaviour over time

Qualitative evidence of changes in pig behaviour

'The pigs are more wild and more difficult to track'.—Respondent 17

'The pigs can smell man; they are getting more wild because they are always getting shot by men'.—Respondent 2

'In the past pigs did not fear men'.—Respondent 25

'They don't come at the same times as they did before'.—Respondent 8

'Before they didn't run; now when I turn on a lamp the pigs run everywhere!'—Respondent 13

'The pigs saw people before and did not run away. It has a sense of who is a hunter and who is not a hunter. Now he is running'.—Respondent 7

'Yes there's a change. The pigs today have already become wild. Pigs today are afraid of men. In the past they wouldn't run from men. It was much easier to hunt pigs in the past'.—Respondent 20

'In the past pigs only looked, but now they run away. Now the pig has got a high school certificate'.—Respondent 4

had not seen large herds or did not know many details about them. Younger hunters typically had never seen or heard of these large groups or long-distance movements.

3.3 | Animal protein consumption patterns in village and urban settings

In village settings, 72% of respondents (n = 32) reported consuming bearded pig weekly or more frequently, 31% of respondents reported consuming bearded pig 2–3 times per week and 22% reported consuming bearded pig four or more times per week (Figure 2). More respondents in village contexts consumed bearded pig meat on a weekly basis than any other animal protein besides domestic chicken (Figure 2). In addition to bearded pig meat, a minority of respondents in village settings reported weekly or more frequent consumption of deer (primarily Sambar deer *Rusa unicolor*, Greater mouse deer *Tragulus napu*, or Lesser mouse deer *Tragulus kanchil*] (7.4%) and other wild meat (18%). Other wild meat consumed in village settings varied widely, and included Malay civet *Viverra tangalunga*, common water monitor *Varanus salvator*, large flying fox *Pteropus vampyrus*, Bornean crested fireback *Lophura ignita*, reticulated python *Malayopython reticulatus* and long-tailed macaque *Macaca fascicularis*.

In city contexts, 50% of respondents (n = 26) reported consuming bearded pig weekly or more often and 38% of respondents reported consuming bearded pig 2–3 times per week, but no respondents

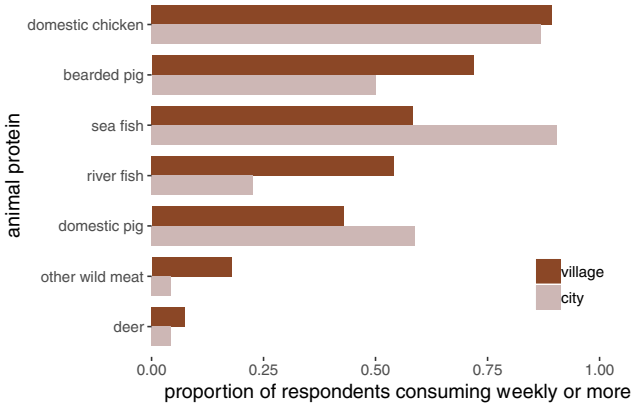

FIGURE 2 Comparison of animal protein consumption by respondents in village (n = 32) and urban (n = 26) contexts

reported eating bearded pig meat four or more times per week. More respondents in urban settings consumed marine fish, domestic chicken and domestic pork than bearded pig. In cities, only 4.3% of respondents reported consuming other wild meat on a weekly or more frequent basis.

3.4 | Hunting declines due to urbanization and other factors

Seven hunters said they hunted less than before due to job commitments, or dynamics related to job opportunities and urban life. Factors tied to urbanization included job-related time commitments, lack of energy due to work and increased travel distance required to hunt.

For example, Respondent 6, who worked as a contractor in Sandakan, said, 'In the past you'd always go hunt, now there's not enough time to hunt'. Respondent 30 noted, 'When you live in the city there are no good places to hunt'. Respondent 2, a rideshare driver in Sandakan, hunted on days off work, but explained that he hunts 'Less now, there are many estates, the forest is remote and the pigs are far away'.

Hunters also reported hunting declines tied to other factors. Three hunters specifically mentioned oil palm-associated land-use change, and related dynamics such as the resulting increase of travel time to hunting locations, as a reason for their reduced hunting frequency. Three hunters also referenced the increased difficulty in finding and/or purchasing ammunition as a reason for reduced hunting.

3.5 | Hunting motivations

Food provision was the most commonly cited hunting motivation (36 respondents, 97% of pool); other major hunting motivations cited were pest control (22, 59%), gift giving (20, 54%) and hobby (19, 51%) (Figure 3). Food provision was also the primary hunting motivation

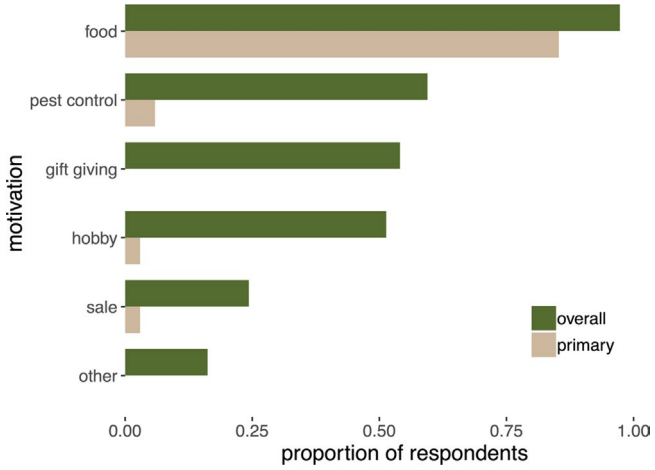

FIGURE 3 Common motivations of respondents ($n = 37$ overall, $n = 34$ primary) to hunt bearded pig. 'Overall' motivations indicate that a motivation was affirmed by a given hunter (regardless of rank order), whereas 'primary' motivations indicate that the motivation was listed as the number one motivation to hunt for that respondent

for the vast majority of respondents (31 respondents, 85%), followed by sale (2, 6%), pest control (2, 6%) and hobby (1, 3%) (Figure 3).

Some hunters were very clear about the importance of bearded pig meat as a central food source. For example, Respondent 15 said, 'It is the main source of food for people who live in the villages' ('*Dia menjadi sumber makanan orang kampung*'). For some hunters, it was important that hunting bearded pig was a way of life. Respondent 9 said that his father taught him that 'This is our life. We live in the forest; this is our food'. As Respondent 25 put it, 'We cannot leave [stop eating] the pig'. ('*Kami tidak boleh tinggalkan babi*'.) For many respondents, hunting bearded pigs was also regarded as an important form of pest control to limit bearded pig disturbance of oil palm plantations (both industrial and smallholder) and garden crops, such as cassava and durian. Multiple hunters also referenced the importance of sharing bearded pig meat communally at parties, weddings, marriages, Christian events and other celebrations, and the community expectations that therefore motivated them to hunt. One hunter shared that during certain months 'there are many requests' [to supply bearded pig meat], due to seasonal parties and celebrations. Several respondents also mentioned satisfaction in their hunting ability; for example, Respondent 5 said, 'Only the village people have what it takes to know what the pig needs' ('*Only the kampung punyai people men know what the babi need bah*').

Selling bearded pig meat for money was cited as a secondary motivation for hunting among a minority of respondents (10 respondents, 27%), followed by respondents citing other motivations (6, 16%). For some hunters who sold bearded pig meat regularly or occasionally, the sale was an important source of income. Hunters generally reported current bearded pig meat prices to be relatively high at roughly 10–15 MYR/kg, in contrast to reported prices of around 3–5 MYR/kg around 10 years ago (much lower than current prices, even when adjusted for inflation). Monthly income from pig hunting was reported to be as high as 5,000 MYR (~1,194 USD) in a good month, substantially higher than wages earned in oil palm plantations. However, respondents expressed mixed perceptions of hunting bearded pig for sale. Some hunters said they never hunted for sale, and felt that selling bearded pig meat was irresponsible because it contributed to pig population declines. Others felt that selling bearded pig meat was unnecessary, or even reprehensible, due to the robust KDM cultural practice of gifting the meat. For example, Respondent 25 captured the sentiment of many KDM hunters towards selling bearded pig meat: 'Don't sell it, if people ask just share it'. ('*Bukan jual lah, kalau orang minta bagi-bagi lah*'.)

3.6 | Hunting technique persistence over time

We found no significant difference in hunting techniques between respondents who began hunting before 1985 and those who began in 1985 or later (Fisher's exact test, $p > 0.99$). Overall, the most popular hunting techniques that respondents had used were (a) on foot with a gun (28 respondents, 83% of respondents) and (b) drive hunts with a gun (25, 75%), although numerous other techniques were also widely used (Figure 4). Hunting with dogs and a spear and hunting with snares were also common among our respondents (Figure 4).

Respondents cited a variety of reasons why they preferred different hunting techniques. For some, hunting location was a major factor in the technique used. For example, hunting on foot with a gun was possible in all habitat types, whereas drive hunts were mentioned in connection with oil palm plantations. Other factors dictating the use of different techniques included success rate, effort and cost required, personal preference, and availability of tools such as guns and ammunition. For example, Respondent 13 commented: 'Who in the world would use a snare when you have a gun!' ('*Mana ada mahu jerat sudah! Ada senapang*'.) Hunting techniques specific to long-distance bearded pig movements were not reported among our respondents.

Hunting success was highly variable, with hunters citing success rates per hunt ranging from roughly 25% to 100%. Hunt lengths generally varied between several hours to a full day or night.

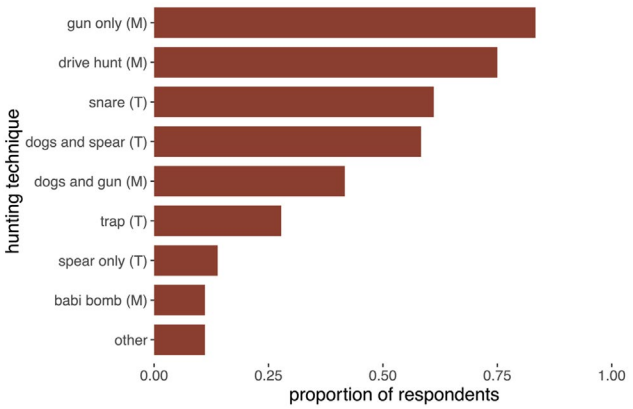

FIGURE 4 Proportion of KDM hunters within respondent pool ($n = 34$) who had used a variety of traditional (T) and modern (M) techniques for hunting bearded pig

3.7 | Regulatory factors influencing contemporary bearded pig hunting practices

Respondents were generally aware of hunting regulations, and knew that permits were required to legally hunt wildlife and sell wild meat. Several hunters shared stories about law enforcement, or referenced permit requirements when explaining their own reasoning about hunting decisions. However, despite their general awareness of the regulatory environment around hunting bearded pig and other species, there was some inconsistency and confusion in understanding permit requirements and hunting regulations. There was also a shared perception that Wildlife Department and Forestry Department officials, among others, were frequently monitoring forest areas for illegal hunting. For example, Respondent 6 said, 'Many of my friends have been fined by the Wildlife Department'.

4 | DISCUSSION

We found several lines of evidence indicating that important hunting practices have been reshaped by oil palm expansion and urbanization. Our results also show that KDM pig hunting motivations and socio-cultural practices continue to be robustly expressed in Sandakan District, Sabah, Malaysian Borneo.

Respondents indicated several distinct themes differentiating hunting practices in oil palm plantations and forest. Additionally, many hunters—particularly older hunters who started hunting before 1985—perceived changes in bearded pig behaviour over time. Hunter dietary patterns also revealed important differences in meat consumption between village and city life. However, hunting motivations and techniques were consistent with past records of hunting practices within Indigenous Bornean communities. Together, these results point to the endurance and transformation of hunting practices within our respondent pool, and suggest a need for long-term hunting management that accommodates meat provision, KDM socio-cultural practices and bearded pig populations.

4.1 | Oil palm-associated changes in contemporary KDM-bearded pig hunting practices

The different characteristics reported between hunting in oil palm plantations and forests indicate an important shift in contemporary KDM hunting practices. With roughly a quarter of Sabah's land area now under plantation agriculture, mostly oil palm (Gaveau, Sheil, et al., 2016), and the majority of our study area under oil palm agriculture (Figure 1), shifting hunting practices in oil palm plantations carry important implications for people and pigs across Sabah. For KDM people, the qualities of the pig hunting experience have already changed substantially. Our respondents noted that hunting in oil palm typically involves more waiting for pigs to forage on oil palm fruits at predictable locations, and that they can more easily see and find pigs in the wider, open environment of an oil palm plantation. Respondents also mentioned that hunting in oil palm plantations is typically easier and less tiring, requiring less walking for extended distances as compared to hunting in forests, and sometimes involving hunting from a car. In Sabah, just two decades ago the vast majority of bearded pig hunting took place in forest contexts and typically on foot with a gun (Bennett et al., 2000), and for millennia across Borneo bearded pig hunting took place in a habitat defined primarily by tropical forests (e.g. Medway, 1964; Prentice et al., 2011). By contrast, many village settings in our study area are located adjacent to, or even within, agricultural landscapes, which are disproportionately associated with higher pathogen infection rates and zoonotic disease emergence (Rohr et al., 2019; Shah et al., 2019). The increase in contemporary bearded pig hunting within oil palm plantations therefore raises important concerns about potential public health risks to KDM pig hunters and communities. For example, in northern Sabah, deforestation and related environmental change have been associated with higher numbers of cases of *Plasmodium knowlesi*, which causes human malaria (Fornace et al., 2016). Future research should investigate whether increased bearded pig hunting within oil palm plantations is linked to increased contact with animal vectors carrying infectious diseases and to higher rates of infectious disease transmission to humans.

Pest control was a common hunting motivation among our respondents, highlighting another major influence of oil palm cultivation on pig hunting patterns. More than half of our respondents cited pest control as a motivation to hunt bearded pigs. Three quarters of our respondents worked in oil palm at some point in their lives, many of them as smallholders and some in industrial oil palm plantations. In both settings, bearded pigs are often regarded as crop pests due to their rooting behaviour, similar to that of the Eurasian wild boar *S. scrofa*, which also damages young oil palm trees in plantations (Jambari et al., 2012; Luskin et al., 2014), with potentially important economic implications. Jambari et al. (2012) also reported pest control of wild boar as an important hunting motivation in oil palm plantations in Peninsular Malaysia.

In addition to the other influences of oil palm cultivation on pig hunting, five respondents noted the different taste of bearded pig meat from oil palm and forest, with three expressing a clear preference for pig meat from forest (e.g. noting the meat tasted sweeter, and/or less smelly, from forest as compared to oil palm plantations). Taken together, our findings suggest that oil palm expansion may be reshaping a variety of environmental, technical, economic and alimentary aspects of contemporary KDM socio-cultural practices linked to bearded pigs.

4.2 | Perceived changes in the behavioural ecology of bearded pigs

When asked if they had noticed a change in bearded pig behaviour over the last several decades, 17 hunters noted that pigs today are '*wilder*' or '*smarter*' —seemingly more skittish—as compared to the past. Respondent 16, for instance, claimed 'In the past they weren't wild, [but] now they are more wild to hunt' ('*Dulu tidak liar, sekarang liar diburu*', where wild means quick to flee or harder to catch).

Similarly, Respondent 3 commented 'They are a bit wilder' ('*Ada liar sikit*') and said 'It means he [the pig] has an IQ' ('*Bermakna dia ada IQ*'). A number of hunters noted that pigs have become increasingly sensitive to hunter presence, including stimuli such as gunshots, gunpowder smell, human smell or headlamp lights. Hunters explained that the pigs respond to these stimuli by fleeing more readily than in the past (Box 1). Rapid fleeing behaviour in response to human hunting has also been recorded in other ungulates, including duikers (multiple species; Croes et al., 2007), reindeer *Rangifer tarandus* (Reimers et al., 2009) and red deer *Cervus elaphus* (Chassagneux et al., 2020).

Further research could investigate the causes and mechanisms of these changes in bearded pig behavioural ecology. High behavioural plasticity, which has been suggested as an adaptive response of red deer in Norway (Lone et al., 2015), could be a mechanism, as could evolutionary selection for individuals with elevated flight response. Further research could also investigate whether habitat fragmentation and oil palm expansion provide a ripe context for these potential mechanisms for behavioural shifts. Our study area in Sabah has high hunting accessibility (Deith & Brodie, 2020), which could elevate the actual or perceived risk to wildlife in the area and create 'landscapes of fear' (Gaynor et al., 2019). Recent ecological evidence from Sabah suggests substantial rates of bearded pig crop raiding in oil palm plantations (Davison et al., 2019; Love et al., 2018), which was widely reported among our respondent pool. We therefore hypothesize that bearded pigs in many parts of Sabah are employing a 'high-risk, high-reward' strategy of feeding on cross-border oil palm fruit subsidies, providing access to high-fat food resources but also elevating predation risk due to human hunting in oil palm plantations (Meijaard et al., 2018), potentially causing elevated flight response in pigs in human-modified landscapes.

Finally, responses from hunters suggest that further research should investigate links between oil palm-associated fragmentation and bearded pig nomadic movements. In our study, several older hunters had seen or heard of movements of large herds of bearded pigs, a behaviour thought to indicate historical patterns of bearded pig nomadism (Caldecott et al., 1993). Younger hunters, however, had typically not observed this aggregating behaviour among bearded pigs. This pattern is consistent with speculation of declines of bearded pig nomadism in the literature due to habitat fragmentation (e.g. Luskin & Ke, 2018). Moreover, oil palm fruit subsidies to bearded pigs—shown to be strongly associated with wild boar feeding and reproduction (Luskin, Brashares, et al., 2017)—could reduce or eliminate the ecological basis for bearded pigs to make nomadic movements at all. As has been shown with logging (Granados et al., 2019), we hypothesize that oil palm-driven habitat fragmentation is causing a reduction in bearded pig responses to mast fruiting events. We also hypothesize that, across Borneo, there is a loss of traditional ecological knowledge of these migrations and hunting practices associated with them (Figure 5). Further research should investigate this hypothesis through social and ecological studies of habitat fragmentation, long-range pig movements, social memory and traditional ecological knowledge.

FIGURE 5 An artistic rendition of what traditional hunting may have looked like during a bearded pig nomadic movement (e.g. Banks, 1949; Mohd-Azlan et al., 2016). Artwork by Amy Koehler and used with permission

4.3 | Urbanization as a driver of changes in contemporary KDM pig hunting practices

Shifted dietary patterns and reduced hunting tied to urbanization reflected important elements of change in our study. In urban contexts, hunter responses suggested that bearded pig was a favoured delicacy but not an indispensable food source given the widespread availability of wild fish and domestic chicken and pork. While bearded pig was the fourth most commonly consumed animal protein for our respondents in urban contexts, in village contexts bearded pig was the second most consumed animal protein (Figure 2). As urbanization increases in Sabah (Cai, 2018), our study suggests that reduction of bearded pig consumption levels in urban contexts may be one way in which reliance on bearded pig meat is lessening in modern times. Additionally, the time commitments related to urban jobs and increased distance from hunting locations resulted in lower hunting for seven of our respondents. The proportion of the Sabah population in gazetted areas of 10,000 people or greater has roughly tripled in the last half century, rising from 16.9% in 1970 to 53.2% in 2005 (Department of Statistics Malaysia, 1977; Department of Statistics Malaysia, 2010; Yaakob et al., 2010). While urbanization could provide new markets for sale of bearded pig meat, on the whole it may be weakening not only consumption of bearded pig meat within the

KDM community but also the hunting relationship that has connected people and pigs across Borneo for millennia (Medway, 1964).

4.4 | Enduring links between historical and contemporary KDM pig hunting practices

While KDM pig hunting practices appear to be changing in important ways, motivations and techniques to hunt bearded pigs spoke to enduring links between KDM communities and pigs. The hunting motivations we recorded among KDM hunters in Sandakan District are in step with the outcomes Bennett et al. (2000) recorded in Sabah and Sarawak, with meat provision as the primary motivation for bearded pig hunting. Presumably, meat provision was also the primary motivation for Indigenous bearded pig hunting across Borneo for millennia, based on archaeological dig sites showing bearded pig bones in sites used for food consumption (Medway, 1964). Additionally, Bennett et al. (2000) found that wild meat presence in rural villager diets was directly related to the abundance of bearded pigs in the forest, and unrelated to alternative sources of food and income. Thus, bearded pigs were generally hunted if they were locally available, whether or not local communities were directly reliant upon them. Some hunters in our study did not rely on bearded pig meat; however, we also encountered several hunters who regarded bearded pig meat as essential to their livelihoods and food security. For example, in describing his motivation to hunt, Respondent 10 said simply: 'It's a matter of survival.' ('*Pasal—untuk survive lah*.') Finally, as there was no significant difference in hunting techniques used by older and younger hunters (i.e. hunters who began hunting before or after 1985), our results suggest that common bearded pig hunting approaches—a blend of modern and traditional techniques (Figure 4)—have likely persisted for at least the last two generations of hunters.

Our findings showed that the bearded pig continues to be a cultural keystone species for the KDM respondents in our study (Garibaldi & Turner, 2004). Respondents emphasized the importance of bearded pig meat at ceremonial and cultural events. Weddings, church events, family gatherings, festivals, birthdays and other celebratory occasions were considered by many hunters to be incomplete without wild meat, typically bearded pig. As Respondent 10 noted: 'The bearded pig is our tradition. For celebrations you only use the bearded pig'. (Note: Other wild game meat is still used by some; for example, one hunter mentioned feral buffalo in connection with celebrations. However, bearded pig meat is indeed standard fare at many KDM cultural events.) Barbecued, sautéed or roasted bearded pig was widely considered a favourite delicacy among our respondent pool, and for many the sharing and consuming of this delicacy constituted a centrepiece of communal celebrations. The significance of bearded pig meat for cultural events is also evident in the high proportion of respondents (54%) who ranked 'gift-giving' as a secondary motivation to hunt. Sharing bearded pig meat, in everyday moments and at special events, has been part and parcel of many Indigenous societies in Borneo (Chin, 2001; Wadley et al., 1997); our results indicate that this species continues to be a cultural touchstone for KDM respondents in our study.

4.5 | Regulatory factors influencing contemporary bearded pig hunting practices

State-wide regulations and enforcement may be playing a role in reducing the frequency of KDM hunting of bearded pigs. As Respondent 12 shared, 'Now, you just buy pig [rather than hunt it yourself] because either you're busy or you're afraid of the law' ('*Sekarang, beli babi jak—sibuk—takut undang-undang*'). Important conservation legislation was passed in the 1990s, requiring licences for hunting bearded pig and other game species (Wildlife Conservation Enactment 1997), and enforcement has increased in many areas of the state (e.g. Latip et al., 2015). Many respondents were aware of hunting regulations, as has been shown for hunters in northern Sabah as well (Wong et al., 2012). We hypothesize that the permitting system and/or enforcement of hunting laws could be influencing the frequency of hunting behaviour in Sabah. While our study was not designed to directly understand this relationship, future work addressing the link between wildlife law enforcement and KDM pig hunting would be a valuable contribution to understanding pathways for sustainable biocultural conservation in Sabah. Adding to dynamics between hunters and law enforcement agencies, in 2020 hunting licenses were frozen by the Sabah Wildlife Department due to the Movement Control Order put in place during COVID-19 (Chan, 2021; The Star, 2021). With the confirmed spread of African Swine Fever to multiple Sabah districts in early 2021, the Wildlife Department maintained the freeze on hunting licences and prohibited the selling of *sinalau bakas*, a popular smoked or barbecued form of wild bearded pig meat (The Borneo Post, 2021). For biocultural conservation of the KDM-bearded pig socio-ecological system, we recommend that local and state government officials and conservation managers consider fair, location-specific management approaches. For example, these approaches might consider rural and urban consumption of bearded pig meat in different ways, or regulate subsistence wild meat consumption by a separate standard from commercial sale. Moreover, these approaches should include local KDM and other Indigenous peoples (Bridgewater & Rotherham, 2019), to elevate their voices, preserve culturally important practices and ensure food security for communities that rely on wild meat and fish.

5 | CONCLUSION

Our results speak to both the endurance and reshaping of historical hunting practices among contemporary KDM communities in Sabah, Malaysia. Several important hunting motivations and techniques were maintained among our respondents, including meat provision as the primary motivation to hunt and hunting with guns

as the primary technique used for bearded pigs over at least the last two generations. However, our findings also indicate that KDM hunting practices have changed substantially, with oil palm plantations: (a) likely providing a more common pig hunting environment than recorded in the past in Sabah and (b) serving as a context for reshaped hunting practices by KDM hunters in our study as compared to their hunting practices in forest. Additionally, urbanization has led to lowered levels of bearded pig meat consumption and less time for some KDM people in our study to hunt bearded pigs. Our results show both the persistence and malleability of Indigenous KDM pig hunting practices. Amidst ongoing oil palm expansion, urbanization-related dynamics and broader political–economic changes, environmental governance initiatives should support robust cultural traditions while ensuring sustainable wildlife populations. Through inclusive, collaborative planning and location-specific regulation, bearded pig management plans can ensure fair access to the meat provision, socio-cultural benefits and pest control supplied by sustainable bearded pig hunting while also ensuring long-term conservation of bearded pig populations, ecological functions and habitat.

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AUTHORS' CONTRIBUTIONS

D.J.K., F.H.S., J.B., J.S.B., M.D.P., M.L. and V.T.J. designed the study; B.G., D.J.K. and F.H.S. obtained the research permissions; J.B. and V.T.J. led data collection, with assistance from D.J.K. and F.H.S.; D.J.K. and M.L. led data analysis; D.J.K., J.S.B., M.D.P., M.L., M.S.L. and L.S.W. wrote the manuscript. All authors contributed to editing the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest to report.

DATA AVAILABILITY STATEMENT

We have archived the de-identified raw data through Dryad Digital Repository at https://doi.org/10.6078/D1CT5V (Kurz et al., 2021).

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ENDNOTE

[1] Women in some communities in Sarawak play significant roles by consuming pig meat, participating in discussions of pig hunts and feeding domesticated pigs (Janowski 2014). Women in our study area in Sabah participate in preparation and consumption of bearded pig meat at meals and community feasts.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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