** This article is now published in *People and Nature*: https://doi.org/10.1002/pan3.10250 **

Title: 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 native bearded pigs (*Sus babatus;* Malay: "babi hutan"), the favored game animal for non-Muslim communities throughout much of Borneo. We conducted 38 semi-structured interviews spanning over 50 hours with bearded pig hunters, asking them about contemporary hunting practices, changes in hunting practices, and patterns of meat consumption.

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. We also documented shifts in dietary meat consumption among our respondents between rural and urban contexts, as well as urbanization-related reductions in hunting frequency. However, despite these substantial changes in hunting practices, numerous KDM motivations, hunting techniques, and socio-cultural traditions have endured over the last several decades.

4. Oil palm has stimulated new hunting practices that differ from those in forests, and has potentially contributed to altered bearded pig behavior due to increased hunting accessibility.

Simultaneously, urbanization has led to changes in dietary patterns, as well as shifted schedules and time availability for hunting. We also note the striking endurance of long-standing KDM pig hunting practices and traditions. We recommend policies that allow flexible, location-specific management approaches to 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. This is particularly important given the recent confirmed outbreak of African Swine Fever (ASF) in numerous forests and districts within Sabah.

Keywords: Borneo, coupled human and natural systems, environmental governance, land use change, socio-ecological systems, Southeast Asia, wildlife management

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 behaviors, 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., Parry et al. 2007, Abernethy et al. 2013, Harrison et al. 2016). Furthermore, land conversion has been shown to influence hunting practices and techniques in a variety of socio-cultural contexts

(Wightman et al. 2002, Luskin et al. 2014). 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 pig hunting practices in Sabah, Malaysia.

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 deeply woven into the socio-ecological fabric of Borneo (Puri 2005, Luskin & Ke 2018). 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 up to 650 km in large herds of up to 300 individuals (Pfeffer 1959, Davies & Payne 1982, Caldecott et al. 1993). Bearded pig meat has been shown to account for 54-97% of wild meat by weight in Indigenous Bornean societies (Bennett & Sompud 2000, Chin 2001, Puri 2005), for whom wild meat can contribute to as much as 36% of meals (Bennett & Sompud 2000). Thus, bearded pig is the most heavily-consumed terrestrial game animal for Indigenous, non-Muslim communities throughout Borneo, and is also widely considered the clear favorite type of wild meat among many of these communities (Bennett & Sompud 2000, Chin 2001, Puri 2005, Janowski 2014).

Bearded pig hunting also carries significant implications for spirituality, recreation, gift-giving, and social practices in many Indigenous Bornean communities (Harrisson 1965, Wadley & Colfer 2004, Janowski 2014). 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: 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).

Bearded pig hunting today takes place within a general context of habitat loss and heterogeneous management policies across its range. Luskin & Ke (2019) estimated significant (20% or more) habitat loss and range reduction from 1990-2010 in each of the three largest historical regions of bearded pig habitat: Peninsular Malaysia, Sumatra, and Borneo. This decline in habitat 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 et al. 2018). While habitat loss is readily quantifiable via tools such as remote sensing and geographic information systems, shifting human-pig interactions, hunting patterns, and related effects on bearded pig populations are more challenging to track and map. Furthermore, a patchwork of multiple legal frameworks regulates hunting across the bearded pig range.

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 Protect Act 1984, Indonesia Act No. 5 of 1990, Sabah Wildlife Enactment of 1997, Sarawak Wildlife Protection Ordinance 1998). Law enforcement capacity also varies by region (Bennett & Sompud 2000, Luskin et al. 2014, Lintangah et al. 2015).

In Sabah, it is legal to hunt bearded pigs and sell the meat with appropriate licenses from the Sabah Wildlife Department (Sabah Wildlife Enactment of 1997). [Note: as of early 2021, hunting licenses remain frozen due to movement control orders related to the COVID-19 pandemic and due to mitigating the spread of the African Swine Fever (ASF) outbreak in Sabah (Chan 2021, The Borneo Post 2021, The Star 2021).] Hunting of bearded pigs in Sabah is widespread in many rural areas, and bearded pig meat remains an important food resource for many human communities (Bennett & Sompud 2000, Mojiol et al. 2013), including those adjacent to oil palm plantations (Wong et al. 2012). Oil palm plantations have shaped bearded pig ecology by reducing the area available for some behaviors (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) (Love et al. 2018, Davison et al. 2019). Research has also shown how bearded pigs benefit from crop-raiding in oil palm plantations (Love et al. 2018, Davison et al. 2019), and has hypothesized that this behavior could potentially increase their populations near oil palm plantations (Luskin et al. 2017, Love et al. 2018, Davison et al. 2019).

These findings raise questions about how bearded pig responses to forest-oil palm mosaics might affect hunting practices. Despite the historical and contemporary prominence of these hunting and dietary relationships—in Sabah, most notably within KDM communities that depend

most heavily on bearded pigs—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. Furthermore, 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).

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 (FAOSTAT 2020). By the early 1980s, oil palm had become Sabah's most important cash crop, fueled 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 hectares (6,867 sq. miles) by 2015; 68% of this total area was converted to oil palm within five years of forest clearance (Gaveau et al. 2016). As of 2015, roughly 24% of Sabah's total land area was covered by oil palm or pulpwood plantations (Gaveau 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 territorialisation, with large plantation corporations taking a capitalist role analogous to their imperialist land-control forbearers and shaping labor 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 labor 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 labor force, consisting of both legal and illegal workers, has become a mainstay of Sabah's plantation economy (Kelly 2011). For their part, Sabahans often take administrative posts within oil palm companies, 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 both croplands and forests in some areas, reducing 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).

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

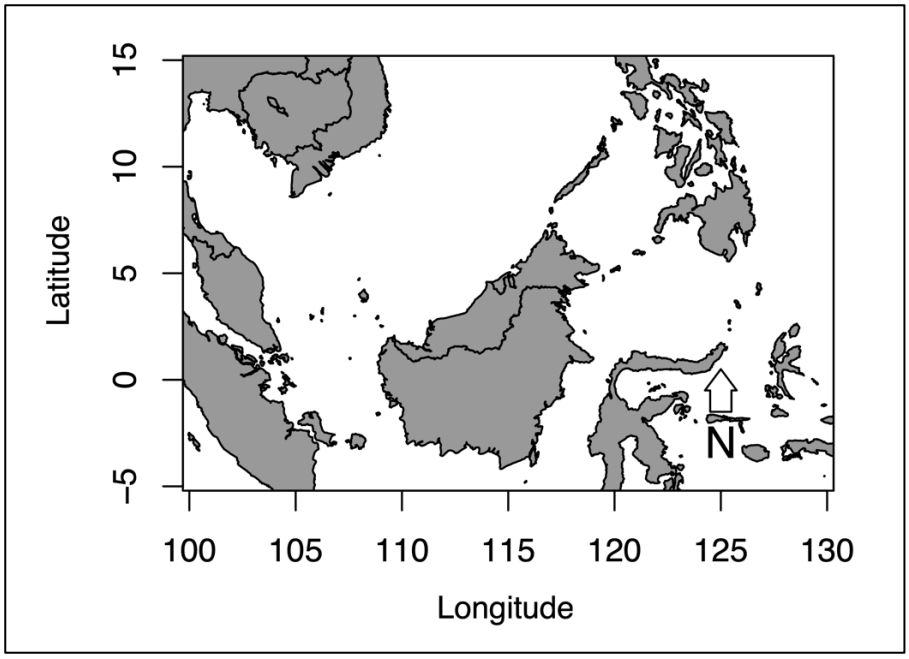
In this paper, we argue that the socio-ecological processes of oil palm expansion and urbanization in Sabah have profoundly shaped—and continue to shape—hunting practices within the influential Kadazandusun-Murut ethnic group (or "KDM", the common shorthand for this community in Sabah). The KDM make 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 assess persistence and change in their hunting practices, perceptions of bearded pig behavior, 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 connect our results to potential biocultural conservation opportunities that encompass both KDM social practices as well as bearded pig conservation.

Methods

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, 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).



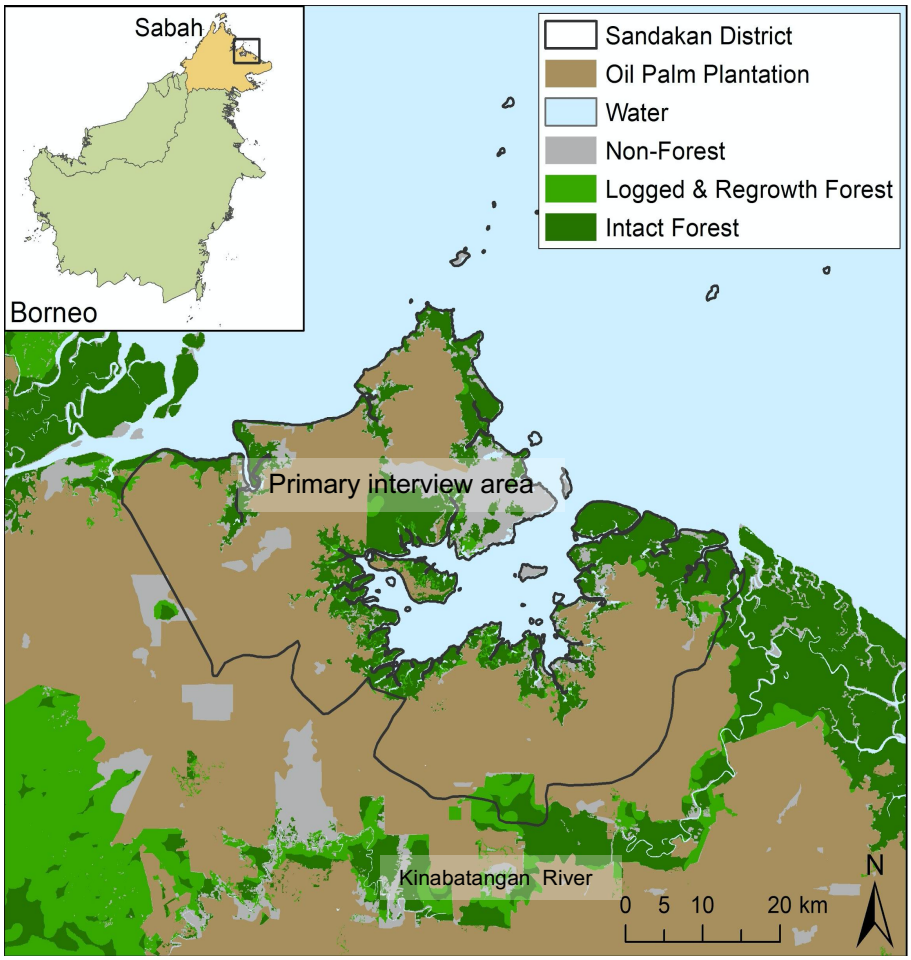


Figure 1. Map of the study area: Sandakan District, Sabah, Malaysian Borneo.

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, we did not encounter any women engaged in hunting over the course of our study.[1] More broadly, hunting has historically been associated with men in Indigenous Bornean societies (Alexander & Alexander 1994, Thambiah 2016). We defined a "hunter" as someone who had hunted bearded pigs twice per year or more, on average, for a span of at least five years of their lifetime. 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. To protect the privacy of respondents, we did not record their names or any audio.

[1]Women in some communities in Sarawak, however, 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.

Two (JB, VTJ) or three (DK, JB, VTJ) 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 (JB, VTJ) spoke fluent Bahasa Melayu, and one of the primary interviewers (VTJ) was a local Sabahan. Each interview lasted from 0.5 - 2.5 hours, 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 Supplementary Material 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 job on hunting, their hunting locations, and bearded pig behavior. Respondents were also asked about differences in their animal protein consumption patterns in village and urban contexts, hunting motivations, hunting techniques, hunting narratives, and hunting success. Most of the questions asked were open-ended, but we also asked closed questions about specific topics in order to gather information about certain categories of interest. To avoid asking for sensitive information and making our respondents uncomfortable, we did not ask whether they had obtained the appropriate licenses 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.

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: subsistence 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*).

Respondent characteristics

Hunter ages ranged from 26 - 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 programs. 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 who answered said they had worked in oil palm agriculture at some point, whether as small holders or in industrial oil palm plantation roles.

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, 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 (Norwana et al. 2011, Gaveau et al. 2016). To test for differences in hunting techniques used between these two categories of hunters, we then conducted a Fisher's exact test in R version 3.6.0 (R Core Team 2019).

Qualitative data were analyzed 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 (Dhee et al. 2019). The themes we chose to analyze were related to our guiding questions of (a) how structural political-economic forces shape interactions between KDM hunters and bearded pigs; and (b) how local sociocultural forces shape the KDM - bearded pig socio-ecological system. To protect respondent identities we associated each interview record with a pseudonym, which we reference with each quote presented. Except where noted, excerpts of interviews have been translated into English, with the original Bahasa Melayu quote sometimes included to present respondent insights in their own language and expression.

Results

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, e.g. because it was 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, Kunol 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 meat from forest. Gompudung 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.”

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	# hunters	Characteristics of hunting in oil palm plantations	# 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

Perceived changes in pig behavior over time

In response to an open-ended question about whether they had noticed any changes in bearded pig behavior since they had started hunting, more than half of all respondents (20/38) noted some type of pig behavior change over time (Box 1). In particular, 17 hunters replied that they noticed that pig behavioral responses 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 behavioral change. Additionally, 5 hunters noted other pig behaviors (e.g. activity patterns) that they perceived to have changed over time. For example, one hunter theorized that pigs change their behavior 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.

Qualitative evidence of changes in pig behavior

"The pigs are more wild and more difficult to track." -Tiansim

"The pigs can smell man; they are getting more wild because they are always getting shot by men." -Sumpi

"In the past pigs did not fear men." -Jempurung

"They don't come at the same times as they did before." -Hendry

"Before they didn't run; now when I turn on a lamp the pigs run everywhere!" -Tamin

"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." -Goruck

"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." -Gompudung

"In the past pigs only looked, but now they run away. Now the pig has got a high school certificate." -Tinggalung

Box 1. English translations (from Malay) of quotations from respondents who perceived changes in bearded pig behavior over time.

Many hunters reported seeing bearded pig eruptions of scores or hundreds of individuals, although many of these observations were by older hunters. Several hunters in our study described these pig eruptions with awe, fear, excitement, and shock. For example, Sumping 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.” Matasing commented, “There are so many pigs that all you can do is just stand and stare until they run away.” Other hunters acknowledged that large herding behavior occurred, but they had not seen large herds and did not know many details about them. Younger hunters typically had never seen or heard of the migrations.

Hunter 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 4 or more times per week. More respondents in village contexts consumed bearded pig meat on a weekly basis than any other meat besides domestic chicken (Figure 2). In addition to bearded pig meat, a minority of respondents in village settings reported at least weekly consumption of deer (7.4%) and other wild meat (18%). Other wild meat consumed in village settings varied widely, including 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 reported eating bearded pig meat 4 or more times per week. However, in city settings, more respondents consumed marine fish, domestic chicken, and domestic pork than

bearded pig. In city contexts, only 4.3% of respondents reported consuming other wild meat on a weekly or more frequent basis.

Hunting declines due to urbanization and other factors

Seven hunters said they hunted less than before due to job commitments, or factors related to job opportunities and urban life. These factors tied to urbanization included job-related time commitments, lack of energy due to work, and increased travel distance required to hunt. For example, Tiko, who worked as a contractor in Sandakan, said, “In the past you’d always go hunt, now there’s not enough time to hunt.” Gintas noted, “When you live in the city there are no good places to hunt.” Sumpi, a rideshare driver in Sandakan, noting that he hunts on his days off work, commented that he hunts “Less now, there are many estates, the forest is remote and the pigs are far away.”

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

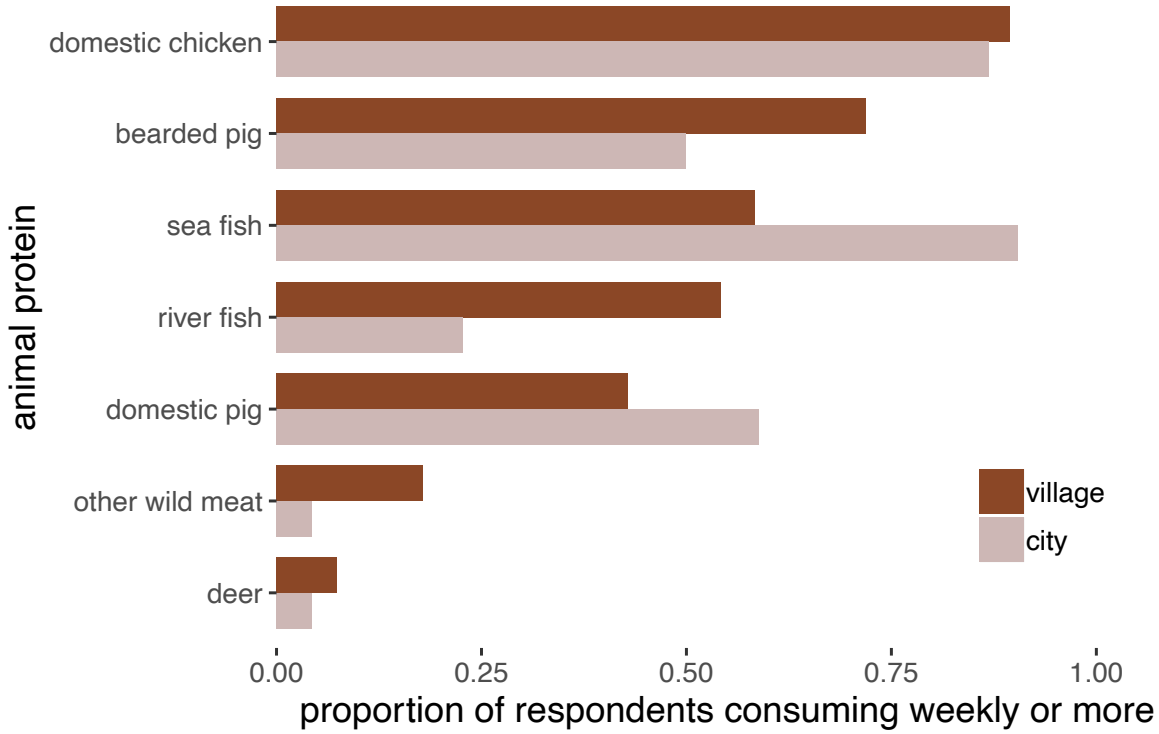


Figure 2. Comparison of animal protein consumption by respondents in village and urban contexts.

Hunting motivations

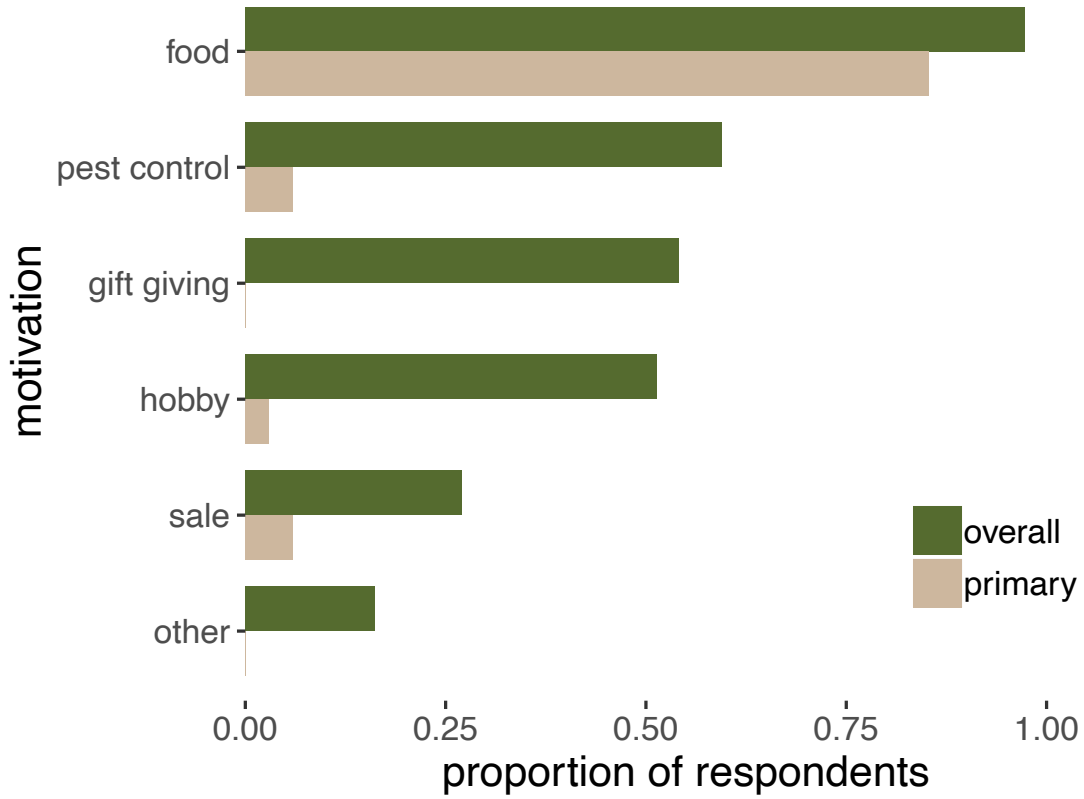
Food provision was the most commonly cited hunting motivation (36 respondents, 97% of pool); other major hunting motivations cited were pest control (22, 59%), gift giving (20, 54%), and hobby (19, 51%) (Figure 3). Food provision was also the primary hunting motivation for the vast majority of respondents (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, Matasing 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. Gasam said that his father taught him: "This is our life. We live in the forest; this is our food." Jempurung responded: "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, Sumping 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%). 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, even reprehensible, due to the robust KDM cultural practice of gifting the meat. For example, Jempurung 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.")* However, for other hunters who sold bearded pig meat regularly or occasionally, the sale was an important source of income. Monthly income from pig hunting was reported to be as high as 5000 MYR (~1,194 US$) in a good month, substantially higher than wages earned in oil palm plantations. Hunters generally reported current bearded pig meat prices to be roughly 10-15 MYR / kilogram, and by contrast reported prices around 3-5 MYR / kilogram around 10 years ago (much lower than current prices, even when adjusted for inflation).

Figure 3. Common motivations of respondents (n = 37) 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 for that hunter.



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 as well as with snares were also common among our respondents.

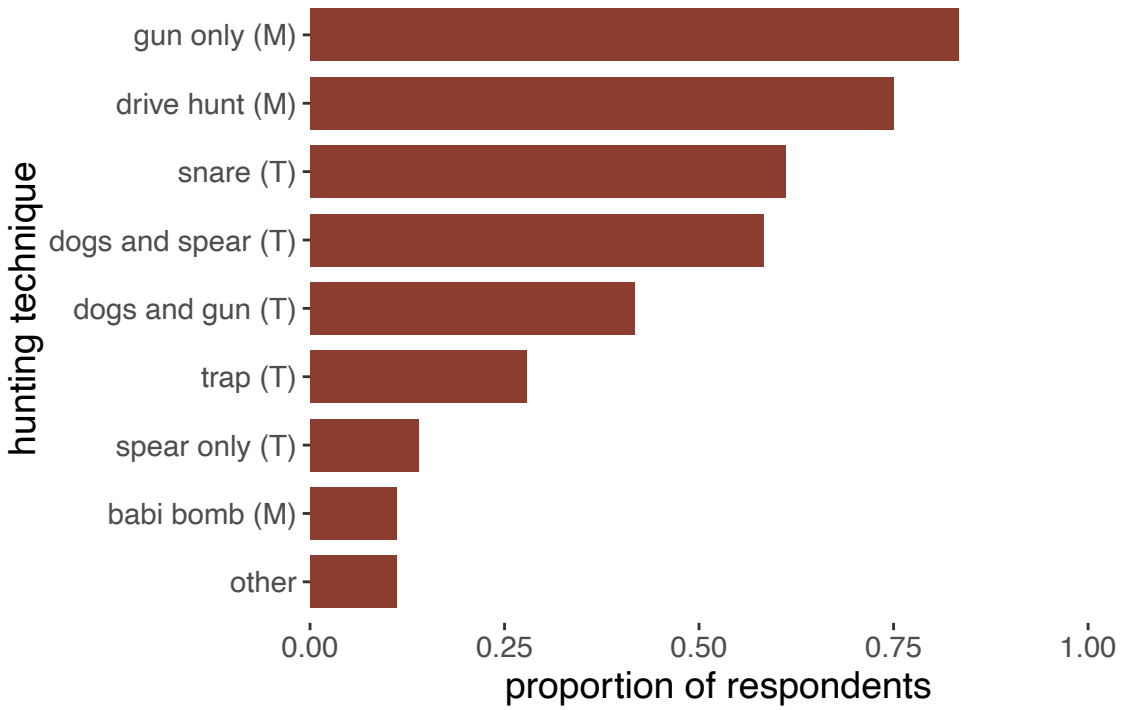


Figure 4. Proportion of KDM hunters within respondent pool (n = 34) who had used a variety of traditional (T) and modern (M) techniques for hunting bearded pig.

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, Tamin 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%. On average, hunters reported success obtaining a bearded pig on 25% - 50% of hunts. Hunt lengths varied between several hours to a full day or night.

Regulatory factors influencing contemporary bearded pig hunting practices

Hunters were generally aware that regulations existed about hunting bearded pigs, and that permits were required to legally hunt wildlife and sell wild meat. Several hunters shared stories about enforcement of these laws, or referenced permit requirements when explaining their own reasoning about hunting decisions. Sometimes respondents shared specific costs associated with hunting permits, which were considered by some hunters to be expensive. However, despite their general awareness of the regulatory environment around hunting bearded pig and other species, there was 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, Tiko said, “Many of my friends have been fined by the Wildlife Department.”

Discussion

We found several lines of evidence indicating that important hunting practices have been reshaped by oil palm expansion and urbanization, as well as results showing that hunting motivations and socio-cultural practices involving consumption of bearded pig meat continue to be robustly expressed in contemporary KDM communities in Sandakan District, Sabah. 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 behavior 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 KDM hunting respondent pool, and suggest a need for hunting that sustain meat provision, socio-cultural practices, and bearded pig populations.

Oil palm expansion as a driver of 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 et al. 2016), and the majority of our study area under oil palm agriculture (Figure 1), increasing and 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 forests (e.g. Medway 1964). 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 zoonose emergence (Shah et al. 2019, Rohr 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.

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; bearded pigs are often regarded as pests in both settings. Bearded pigs are regarded as pests within oil palm plantations (Meijaard et al. 2018); this is due to their rooting behavior, similar to that of the wild boar, 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) recorded pest control of wild boar as an important motivation for oil palm workers hunting for consumption and sale in plantations in Peninsular Malaysia. Our results indicate a similar pattern for pest control as a secondary motivation for pig hunting among our study population of KDM hunters in Sabah. 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 less smelly, from forest as compared to oil palm plantations). This partiality for bearded pig meat has been reported elsewhere in the literature (e.g. Bennett et al. 2000, Janowski 2014). Taken together, these findings suggest that oil palm expansion is reshaping a variety of environmental, technical, economic, and alimentary aspects of contemporary KDM pig hunting and cultural practices.

Perceived changes in the behavioral ecology of bearded pigs

When asked if they had noticed a change in bearded pig behavior over the last several decades, 17 hunters noted that pigs today are *"wilder"* or *"smarter"* —seemingly more skittish— as compared to the past. Janji, 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, Bukarak commented "They are a bit wilder" *("Ada liar sikit"*)

563 and said “It means he [the pig] has an IQ” (“*Bermakna dia ada IQ”*). A number of hunters noted
564 that pigs have become increasingly sensitive to hunter presence, including stimuli such as
565 gunshots, gunpowder smell, and headlamp lights. Hunters explained that the pigs responded to
566 these stimuli by fleeing more readily than in the past (Box 1). Rapid fleeing behavior in response
567 to human hunting has also been recorded in other ungulates, including duikers (Croes et al.
568 2007), reindeer (Reimers et al. 2009), and red deer (Chassagneux et al. 2020).
569
570 Further research could investigate the causes and mechanisms of these changes in bearded
571 pig behavioral ecology. High behavioral plasticity, which has been suggested as an adaptive
572 response of red deer in Norway (Lone et al. 2015), could be a mechanism, as could
573 evolutionary selection for individuals with elevated flight response. Further research could also
574 investigate whether habitat fragmentation and oil palm expansion is a potential cause of this
575 behavioral shift. Our study area in Sabah has high hunting accessibility (Deith & Brodie 2020),
576 which could elevate the actual or perceived risk to wildlife in the area (Gaynor et al. 2019).
577 Recent ecological evidence from Sabah suggests substantial rates of bearded pig crop raiding
578 in oil palm plantations (Love et al. 2018, Davison et al. 2019), which was widely reported
579 amongst our respondent pool as well. We therefore hypothesize that bearded pigs in many
580 parts of Sabah are employing a “high risk, high reward” strategy of feeding on cross-border oil
581 palm fruit subsidies, providing access to high-fat food resources but also elevating risk due to
582 human hunting in oil palm plantations, potentially causing elevated flight responses in pigs.
583 Finally, responses from hunters suggest further research should investigate links between oil
584 palm-driven fragmentation and bearded pig nomadic movements. In our study, several older
585 hunters had seen or heard of movements of large herds of bearded pigs, a behavior thought to
586 indicate historical patterns of bearded pig nomadism (Caldecott et al. 1993). Younger hunters,
587 however, had typically not observed this aggregating behavior amongst bearded pigs. This
588 pattern is consistent with speculation of declines of bearded pig nomadism in the literature due

589 to habitat fragmentation (e.g. Luskin & Ke 2018). Moreover, oil palm fruit subsidies to bearded
590 pigs in many areas—as shown with wild boar (*Sus scrofa*) (Luskin et al. 2017)—could reduce or
591 eliminate the ecological basis for bearded pigs to make nomadic movements at all. As has been
592 shown with logging (Granados et al. 2019), we hypothesize that oil palm-driven habitat
593 fragmentation is causing a reduction in bearded pig responses to mast fruiting events, as well
594 as the loss of traditional ecological knowledge of these migrations and hunting practices
595 associated with them. Further research should investigate this hypothesis through social and
596 ecological studies of habitat fragmentation, long-range pig movements, social memory, and
597 traditional ecological knowledge.
598
599 *Urbanization as a driver of changes in contemporary KDM pig hunting practices*
600 Shifted dietary patterns and reduced hunting tied to urbanization reflected important elements of
601 change in our study. In urban contexts, hunter responses suggested that bearded pig was a
602 favored delicacy but not an indispensable source of food given the widespread availability of
603 wild fish and domestic chicken and pork. While bearded pig was the fourth-most commonly
604 consumed meat source for our respondents in urban contexts, in village contexts bearded pig
605 was the second-most consumed meat source (Figure 2). As urbanization increases in Sabah
606 (Cai 2018), our study suggests that reduction of bearded pig consumption levels in urban
607 contexts may be one way in which reliance on bearded pig meat is lessening in modern times.
608 Additionally, the time commitments related to urban jobs and increased distance from hunting
609 locations resulted in lower hunting for seven of our respondents. The proportion of the Sabah
610 population in gazetted areas of 10,000 people or greater has roughly tripled in the last half
611 century, rising from 16.9% in 1970 to 53.2% in 2005 (Department of Statistics Malaysia 1977,
612 Department of Statistics Malaysia 2010, Yaakob et al. 2010). Urbanization may be weakening
613 not only consumption of bearded pig meat within the KDM community, but also the hunting

614 relationship that has connected people and pigs across Borneo for millennia (Medway 1964,
615 Harrison 1998).
616
617 *Enduring links between historical and contemporary KDM pig hunting practices*
618 While KDM hunting practices appear to be changing in important ways, motivations and
619 techniques to hunt bearded pigs spoke to enduring links between KDM communities and pigs.
620 The hunting motivations we recorded among KDM hunters in Sandakan district are in step with
621 the outcomes Bennett & Sompud (2000) recorded in Sabah and Sarawak, with meat provision
622 as the primary motivation for bearded pig hunting. Presumably meat provision was also the
623 primary motivation for Indigenous bearded pig hunting across Borneo for millennia, based on
624 archaeological dig sites showing bearded pig bones in sites used for food consumption
625 (Medway 1964). Additionally, Bennett & Sompud (2000) found that wild meat presence in rural
626 villager diets was directly related to the abundance of bearded pigs in the forest, and unrelated
627 to alternative sources of food and income. Thus, bearded pigs were generally hunted if they
628 were locally available, whether or not local communities were directly reliant upon them. Some
629 hunters did not rely on bearded pig meat; however, we also encountered hunters who regarded
630 bearded pig meat as essential to their livelihoods and food security. For example, in describing
631 his motivation to hunt, Gitom said simply: “It’s a matter of survival.” *(“Pasal – untuk survive lah.”*)
632 Finally, as there was no significant difference in hunting techniques used by older and younger
633 hunters (i.e. hunters who began hunting before or after 1985), our results suggest that common
634 bearded pig hunting techniques—a blend of modern and traditional techniques (Figure 4)—have
635 likely persisted for at least the last two generations of hunters.
636
637 The ceremonial and communal importance of bearded pig meat remained central for the KDM
638 respondents in our study. Weddings, church events, family gatherings, festivals, birthdays, and
639 other celebratory occasions were considered by many hunters to be incomplete without wild

meat, typically bearded pig. As Gitom 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, feral buffalo was also mentioned 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 favorite delicacy among our respondent pool, and for many the sharing and consuming of this delicacy constituted a centerpiece 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 life and in special life events, has been part and parcel of many Indigenous societies in Borneo (Wadley et al. 1997, Chin 2001); our results indicate that this species continues to be a cultural touchstone today.

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 Jay shared, *“Sekarang, beli babi jak – sibuk – takut undang-undang”* (“Now, you just buy pig because either you’re busy or you’re afraid of the law”). Many respondents were aware of hunting regulations, as has been shown for hunters in northern Sabah as well (Wong et al. 2012). Important conservation legislation requiring licenses for hunting bearded pig passed in the 1990s (Sabah Wildlife Enactment of 1997), and enforcement has increased in many areas of the state (e.g. Latip et al. 2015). We hypothesize that the permitting system and/or enforcement of hunting laws could be influencing the frequency of hunting behavior in Sabah. While our study was not designed to directly understand this relationship, future work addressing the relationship between wildlife law enforcement and KDM pig hunting would be a valuable contribution to understand sustainable biocultural conservation in Sabah. Adding to this dynamic, 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 has maintained the freeze on hunting licenses and prohibited the selling of *sinalau bakas*, a popular smoked form of wild bearded pig meat (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 flexible and location-specific management approaches. These approaches should include local KDM and other Indigenous peoples to identify and preserve culturally important practices (Bridgewater & Rotherham 2019).

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 amongst our respondents, including meat provision as the primary motivation to hunt and hunting with guns as the primary technique used for bearded pigs. However, our findings also indicate that KDM hunting practices have changed substantially, with oil palm plantations as (a) a more common hunting environment than recorded in the past in Sabah; and (b) a context for reshaped hunting practices by KDM hunters in our study as compared to hunting practices in forest. Additionally, urbanization has led to lowered levels of bearded pig meat consumption and less time for some KDM people to hunt bearded pigs. Our study has shown both the persistence and malleability of Indigenous KDM pig hunting practices. Amidst ongoing oil palm expansion, urbanization dynamics, and broader political-economic changes, environmental governance initiatives should support these cultural traditions while ensuring sustainable bearded pig populations. Through robust collaborative planning and flexible regulation, bearded pig management plans can ensure fair access to the meat provision, socio-cultural benefits, and pest control from sustainable bearded pig hunting, while also ensuring long-term conservation of bearded pig populations, ecological functions, and habitat.

Acknowledgements

We dedicate this paper to Mr. Peter Malim, a kind person and a dedicated representative of wildlife conservation interests in Sabah for many years. Thank you to Andre Pinassi Antunes, Andrew J. Marshall, and an anonymous reviewer for comments that greatly improved the manuscript. Thank you to Kate Montana and Wendy Ooi for help with reading, organizing, and discussing themes from the background literature. Thank you to Evelyne St-Louis for creating Figure 1, and for advice on structure and framing. Thank you to the UC Berkeley Undergraduate Research Apprenticeship Program, the Sponsored Projects for Undergraduate Research program, and the College of Natural Resources Travel Grant for summer funding for JB. DJK is grateful to the SJ Hall Fellowship, the Hannah M. and Frank Schwabacher Memorial Scholarship Fund, the Howard William Siggins Fellowship, the Philomathia Graduate Student Fellowship in the Environmental Sciences, the Harvey Fellowship, and the Institute of East Asian Studies for funding that supported this work. We are grateful to the Brashares Lab and Potts Lab for feedback on this project at various stages of analysis and writing. Thank you to the Sabah Biodiversity Centre for permission to conduct fieldwork in Sabah (Licence Ref.No. JKM/MBS.1000-2/2 JLD.9 (59)), and thank you to Mr. Johny Ronggitom and the Sandakan Municipal Council for permission to conduct interviews in Sandakan (Ruj.MPS100-48/001/0000/035). Most of all, thank you to the hunters who welcomed us into their communities, spent time with us, and shared their rich experiences with us – we are very grateful.

Data availability statement

We have archived the de-identified raw data through Dryad Digital Repository at https://doi.org/10.6078/D1CT5V.

Author contributions

DJK, FHS, JB, JSB, MDP, ML, and VTJ designed the study. BG, DJK, and FHS obtained research permissions. JB and VTJ led data collection. DJK, JSB, MDP, ML, MSL, and LW wrote the manuscript. All authors contributed to editing the manuscript.

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