Trends in the bushmeat market trade in North Sulawesi and conservation implications

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Abstract*:*

The bushmeat trade, or the trade in wild animals for meat, is a primary threat to wildlife and ecosystems in Sulawesi, Indonesia. Hunting for trade and consumption can hasten the local extirpation of vulnerable species, such as fruit bats and the protected babirusa and Sulawesi crested black macaque. This study provides a much-needed step in understanding the bushmeat trade by describing longitudinal trends in the amount of bushmeat (animal carcasses) observed for sale in markets in North Sulawesi, a particularly biodiversity rich area. Surveys were conducted in 10 markets in 2011, 2015, 2018 and 2019. At each market, total counts of all taxa for sale were noted, and encounter rates per market sample were derived to account for variable sampling effort across years and markets. Generalised Linear Mixed Models were used to compare encounter rates across years, months, and markets. Our results show that although animal carcasses are still sold in high numbers, there has been an overall decrease between 2011 and 2019, particularly between 2011 and 2018 (encounter rate fell by 93%). However, bats, rats and Sulawesi warty pigs were still present at high levels, indicating a persistent demand for bushmeat in North Sulawesi. The encounter rate of protected taxa for sale was low, but steady throughout the study period. We identified which markets sold the greatest amount of bushmeat to inform future conservation actions and management. Based on our results, the persistent demand for bushmeat in the region, and the continued presence of protected taxa in the markets, we recommend further research to establish the sustainability of the bushmeat trade at its current rate.

Key words: wildlife trade, wild meat, Sulawesi, hunting, protected species

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1. Introduction

Hunting is a key driver of wildlife extinction and has caused dramatic population declines worldwide (Bennett et al., 2002; Benítez-López et al., 2017; IUCN, 2019). Hunting has been identified as the biggest threat to biodiversity in South East Asia, where practices such as wildlife snaring have resulted in a huge loss of vertebrate diversity and abundance in areas of the world already threatened by deforestation, agricultural expansion and human-wildlife conflict (Harrison et al., 2016; Gray et al., 2018; Tilker et al., 2019). Some species are more vulnerable to hunting than others (e.g. Branch, Lobo, & Purcell, 2013; Sheherazade & Tsang, 2015), however, the scale of wildlife extraction is such that it affects all tropical biota (Bennett et al., 2002; Galetti & Dirzo, 2013).

Hunting wild animals to trade for meat, or 'bushmeat', is a significant issue in Sulawesi, Indonesia. Rejeki (2018) estimates a minimum of 83,000 tonnes of bushmeat is harvested every year with the highest reported rates of consumption in North Sulawesi. Globally, drivers of the bushmeat trade range from subsistence hunting and nutrition (Fa, Ryan, & Bell, 2005), to demand as a luxury commodity with cultural or traditional ties associated with recreation and health (Drury, 2009; Ripple et al., 2016; Flora and Fauna International, 2018). However, North Sulawesi has a generally high nutritional and caloric intake, and the cost of bushmeat is broadly similar to that of domestic meat (Latinne et al. 2020). As such, bushmeat consumption is not generally associated with subsistence or sustenance in the region (O'Brien & Kinnaird, 2000; Lee, 2005), nor is it an expensive luxury. Rather, it is perceived as a food for special occasions, thought to be consumed most commonly during celebration periods like Christmas, New Year, Thanksgiving and Easter; particularly in the Minahasa region where the majority of the population are Christian (Clayton & Milner-Gulland, 2000; Lee et al., 2005; Sheherazade & Tsang, 2015; Latinne et al., 2020). Across North Sulawesi, populations of fruit bats (*Pteropus* sp., *Acerodon* sp.), anoa (*Bubalus depressicornis),* babirusa (*Babyrousa celebensis*), and crested black macaques (*Macaca nigra*) have declined sharply, with anoa and babirusa now extirpatedfrom areas where they were once abundant e.g., Tangkoko Nature Reserve and Manembo-nembo Wildlife Reserve (Clayton & Milner-Gulland, 2000).

The IUCN Red List of Threatened Species (IUCN 2020) cites hunting for food and trade in bushmeat as one of the main threats to many of Sulawesi's endemic species, including anoa (Burtonet al, 2016), babirusa (Leus et al., 2016), crested black macaques (Supriatna & Andayani, 2008), bearcuscus (*Ailurops ursinus*) (Salas et al., 2019), and dwarf cuscus (*Strigocuscus celebensis*) (Helgen et al.,2020). Consequently, it is illegal to hunt, kill or trade these protected species under Indonesian law(Act of the Republic of Indonesia, No.5 of 1990. Article 21; Government Act Number 7 year, 1999). Inaddition, non-protected species can only be traded with a permit, within the constraints of a legally mandated quota for inter-provincial trade set by the Indonesian Institute of Sciences and Natural Resources Conservation Agency (Government Act Number 8 year, 1999) (President RI., 1999b). As there is currently no hunting quota for some frequently traded taxa, such as bats in Sulawesi, trading them is technically illegal (Ministry of Environment and Forestry, 2020). Enforcement of these laws is widely regarded as inadequate (Lee et al., 2005; Pangau-Adam, Noske, & Muehlenberg, 2012), with some hunters and traders suggesting that the risk of enforcement is too low to discourage hunting and trading illegally (Latinne et al., 2020). Other conservation efforts in the region have included awareness-raising campaigns conducted by NGOs, including Selamatkan Yaki ("Save the Sulawesi crested black macaque"), with the aim of encouraging pride in endemic wildlife and educating people about the risks associated with bushmeat consumption (KLHK, 2019).

Several studies have investigated the bushmeat trade in North Sulawesi over the last 20 years (e.g., Clayton & Milner-Gulland, 2000; Lee et al., 2005; Sheherazade & Tsang, 2015; Rejeki, 2018; Latinne et al., 2020), using methods that include hunter, trader, and consumer interviews, and quantitative market and roadblock surveys, i.e., counts of animals confiscated along common wildlife trade

routes. These approaches offer different, complementary insights into the complex bushmeat trade: For example, while qualitative interviews may illuminate the underlying socio-economic drivers of bushmeat hunting and consumption (Rejeki, 2018; Sheherazade & Tsang, 2015), they do not provide measurable information about the scale and scope of the trade itself (McNamara et al., 2016). A recent study (Latinne et al., 2020) provided valuable information on the volume of bushmeat traded in North Sulawesi over a four month period (November 2018 through February 2019), highlighting the importance of quantifiable measures of trade activity upon which to base appropriate conservation interventions. Quantitative, longitudinal data are essential to meaningfully assess the extent of the trade, and to monitor the impact of conservation efforts (Fa & Brown, 2009; McNamara et al., 2016).However, there are currently no published data quantifying the bushmeat market trade over a long period of time in North Sulawesi.

In order to address this absence, quantitative bushmeat market surveys were conducted throughout North Sulawesi in 2011, 2015, 2018 and 2019. The aim was to document trends in the amount of bushmeat observed for sale over the eight year period (Objective 1); to determine the ongoing presence of protected taxa sold in the markets (Objective 2); and to identify any significant relationships between bushmeat trade and seasonality or market location (Objective 3). This longitudinal information will help build a more comprehensive picture of trade in the region that can inform conservation interventions where necessary.

2. Methods

2.1 Data collection:

Surveys were conducted in 2011, 2015, 2018, and 2019 at 10 traditional markets within the Minahasa, North Minahasa, South Minahasa and Bolaang Mongondow regencies, as well as Bitung city and Tomohon, in North Sulawesi (Fig. 1) for a total of 112 days (Survey effort detailed in Supporting Information Appendix S1). Markets were selected based on anecdotal evidence of wild meat trade in the area (pers. obs Siwi).

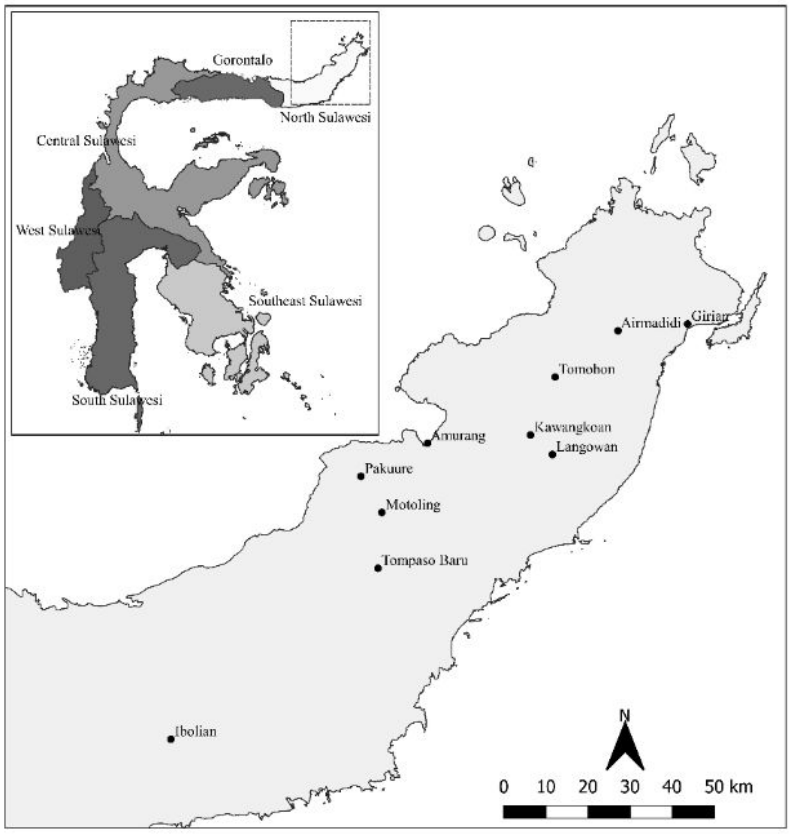


Figure 1: Survey market locations in North Sulawesi. Basemap source: igismap (2020)

Month	2011	2015	2018	2019	Total by month
Jan[a]	-	-	-	-	-
Feb	0	0	0	9	9
Mar	6	0	0	0	6
Apr	0	0	0	9	9
May	5	0	0	0	5
Jun	0	4	0	0	4
Jul	0	9	0	6	15
Aug	5	0	10	0	15
Sep[a]	-	-	-	-	-
Oct	15	0	9	0	24
Nov	10	0	0	0	10
Dec	5	0	10	0	15
Total by year	**46**	**13**	**29**	**24**	**112**

Table 1: Bushmeat survey days by month and year. No sampling was carried out in months with superscript due to logistical reasons [a].

Multiple surveys were conducted in 2011, 2015, 2018, and 2019 (Table 1), with survey effort concentrated into monthly blocks. Differences in survey effort were accounted for in all analyses by using animal carcass encounter rates rather than counts. Observations were made during market opening hours between 06:00 -10:00 on popular market days (usually Saturdays). Two surveyors collected data in each location by walking through the market and counting every animal carcass. In each case surveyors recorded the following: Type, to a species level where identification was possible; number of individuals sold per species; and price per kilogram (kg). In cases where species-level identification was not possible (e.g. due to charring of the carcasses), animals were classified into more general categories. We were unable to identify fruit bats, squirrels, rails and some macaques to species levels (See Supporting Information Appendix S2). Surveyors only recorded what they observed for sale openly at the markets; bushmeat sold discretely would not have been recorded.

2.2. Data Analysis:

To model the number of animals observed for sale as a function of year, we used the package "lme4" (Bates et al., 2015) to fit a Poisson GLMM (Generalized Linear Mixed Model) with a log link. The Poisson distribution is typically used for count data and the log link function ensures positive

fitted values (Zuur et al., 2009). Year was treated as a fixed covariate (factor with four levels: 2011, 2015, 2018, 2019). To incorporate the dependency among counts of the same taxa at the same markets, taxa nested within market was used as a random intercept. Taxa was included to account for the consistency in the number of animals observed for sale by taxa (e.g., consistently high numbers of bats) and by market (i.e., some markets regularly sold more or less of certain taxa than others). An observation level random effect (OLRE) was included to account for overdispersion (Harrison et al. 2018). Because markets were not evenly sampled within or between years (Table 1) an offset term (the logarithm of sampling effort per year) was included to account for differences in sampling effort. This allowed us to model the encounter rate of animal carcasses for sale per market sample and avoid the bias introduced by differing sampling effort across years. To model the number of animals of
protected taxa observed for sale as a function of year we used the same structure but omitted the random effect of taxa because its inclusion resulted in model instability. We used the same model structures to model the numbers of individual taxa observed for sale as a function of year. To model the number of animals observed for sale as a function of month we used a Poisson GLMM with a log link. Fixed covariates were month (factor with 9 levels) and year (factor with 4 levels). We included the logarithm of sampling effort per month as an offset, and taxa nested in market, crossed with an OLRE term as random intercepts.

To model the number of animals of protected taxa observed for sale as a function of month we used the same structure, but as with the protected taxa by year analysis, we removed the taxa random effect. No overdispersion was observed with this model so the OLRE was omitted.

To model the encounter rate of animals observed for sale as a function of market we fit another Poisson GLM with log link and included the logarithm of sampling effort per market as an offset term. Fixed covariates were market (factor with nine levels) and year (factor with four levels). We included the interaction between market and year to account for potential annual fluctuations in market activity and included taxa and an OLRE as crossed random intercepts.

Two linear mixed models (LMM) were used to model the price (per kg) of animals observed for sale as a function of year; one examining all taxa together and the other examining protected taxa alone. The fixed covariate in both models was year (factor with 4 levels), and market was included as a random intercept in both models. All analyses were carried out using the software R version 3.6.1 (R Core Team, 2019).

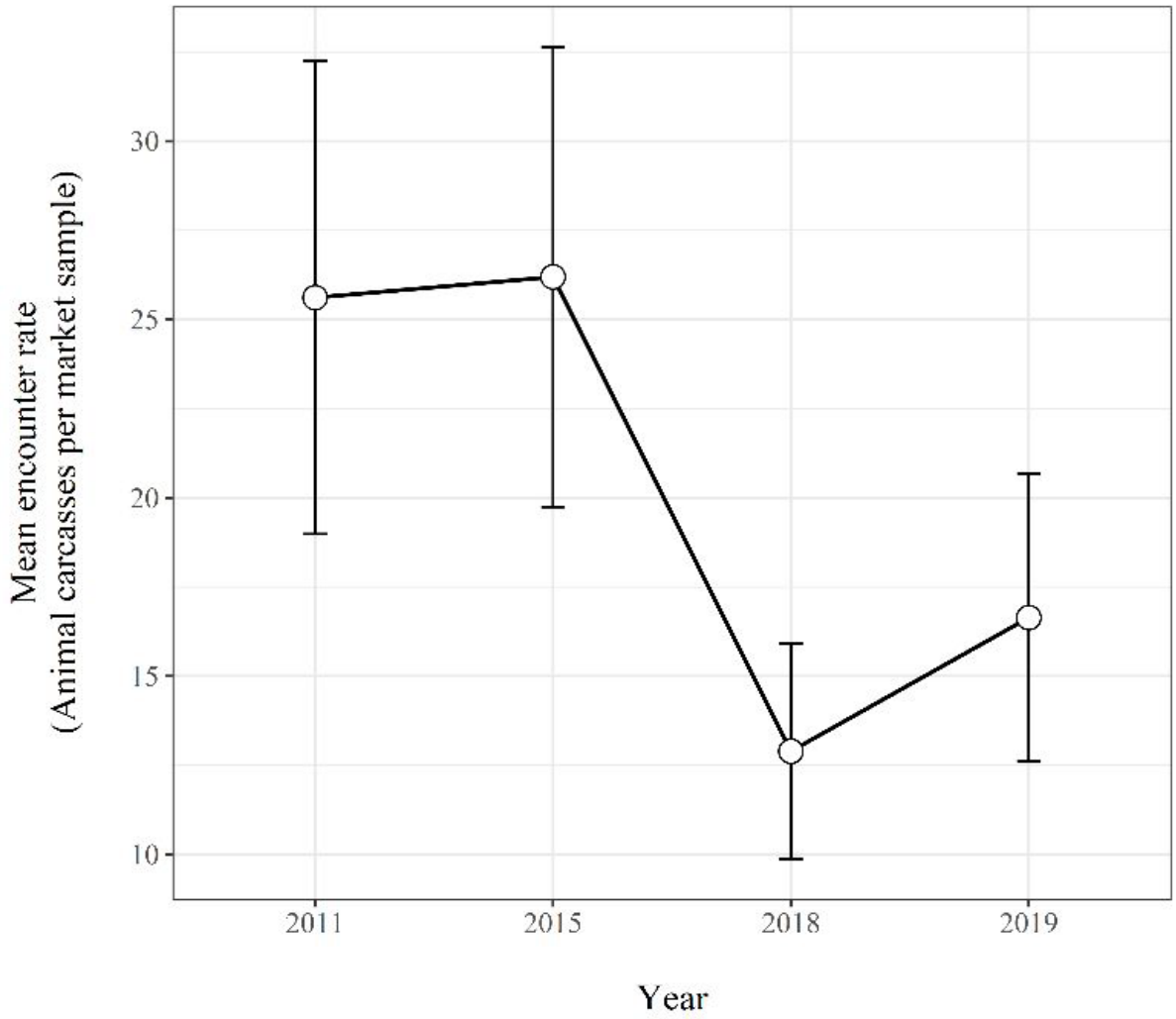
3. Results:

We recorded 33,129 individual animal carcasses for sale in markets from 17 taxa (Supporting Information Appendix S2). The number of taxa observed for sale in the markets increased from nine in 2011 to 12 in 2019. Fruit bats, large rats (*Rattus sp./Paruromys dominator*) and Sulawesi warty pigs (*Sus celebensis*) were the most heavily traded taxa, accounting for 50%, 37% and 6% of total observations (Supporting Information Appendix S2). Although animals were sold in high numbers in markets in 2019, the raw survey results show an overall decrease in animals observed for sale since the beginning of data collection in 2011. Protected species were consistently observed in much lower numbers than non-protected species.

3.1. Objective 1: Count observed by year

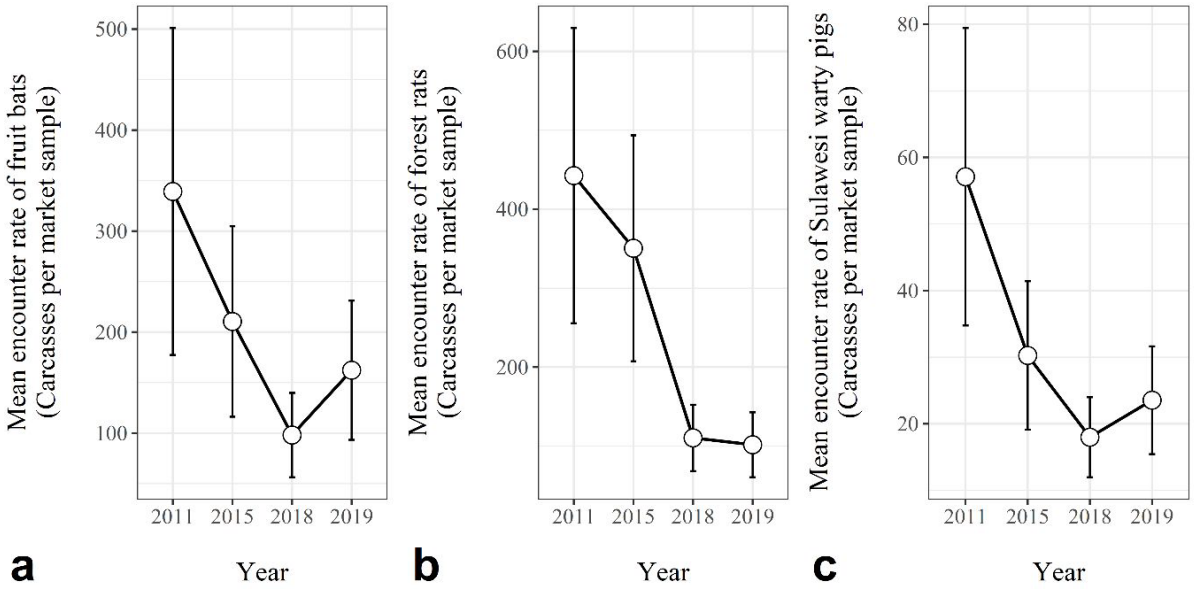
After adjusting for differing annual survey effort, the encounter rate of animal carcasses per market sample differed significantly by year (Likelihood ratio test (LRT); $\chi2(3)=20.804$, $p<0.001$). Whenrate ratios are converted into percentage change, there was a statistically significant decrease of 99% in encounter rate in 2018 compared to 2011 (Tukey HSD; $p=0.003$), with a significant decrease of 103% in 2018 compared to 2015 (Tukey HSD; $p<0.001$). An apparent increase in the encounter rate was

recorded in 2019 compared to 2018, although this difference was not statistically significant at α=0.05 level after adjusting for multiple testing (Fig. 2).



15 Figure 2. Mean encounter rate (by year) of animal carcasses (per market sample) in bushmeat markets in North Sulawesi in 2011, 2015, 2018 and 2019. Error bars represent the standard error of the mean.

After accounting for differences in survey effort, the encounter rate per market sample for seven of the taxa changed significantly by year, including the Sulawesi warty pig, monitor lizard (*Varanus salvator)*, bear cuscus, fruit bat, large rat, squirrel (*Prosciurullus sp.*), and rails (*Gallirallus sp*.) (Supporting Information Appendix S2). The encounter rate of fruit bats changed significantly between years (LRT; $\chi2(3)=13.268$, $p=0.004$) with a decrease of 255% observed between 2011 and 2018 (Tukey HSD; $p=0.003$) (Fig. 3a). A significant decrease was also observed between 2011 and 2018 for large rats (LRT: $\chi2(3)=25.897$, $p<0.001$: Tukey HSD; $p<0.001$) and Sulawesi warty pigs (LRT; $\chi2(3)=13.670$, $p=0.003$: Tukey HSD; $p=0.002$) (Figs. 3b and 3c). Non-significant increases in the encounter rate of fruit bats and Sulawesi warty pigs were observed between 2018 and 2019 (Figs. 3a and 3c).



13 Figure 3. Mean encounter rate (by year) of animal carcasses (per market sample) in bushmeat markets in North Sulawesi in 2011, 2015, 2018 and 2019. a) fruit bats, b) forest rats, c) Sulawesi warty pigs. Error bars represent the standard error of the mean.

3.2. Objective 2: Protected taxa by year

Protected taxa comprised 0.8% of the bushmeat observed for sale across the sampling period (272 individuals from a total of 33,129), and after accounting for differences in annual survey effort, the analysis indicated no statistically significant change in the encounter rate between years (LRT; $\chi2(3)=0.571$, $p=0.903$). In 2011, 2015, 2018 and 2019 the percentage of protected taxa observed was 0.51%, 0.27%, 2.27% and 0.90% of total taxa observed respectively. The dwarf cuscus was the most heavily traded protected taxa in 2011, 2018, and 2019, followed by the bear cuscus, and the Sulawesi crested black macaque (Fig. 4). It should be noted that the non-significant increase in protected taxa observed for sale in 2018 was almost certainly the result of a single encounter of 22 macaques for sale at one market location. As such, the rise in 2018 should not be interpreted as indicative of an upward trend, but rather as representative of an unusual, but meaningful outlier event.

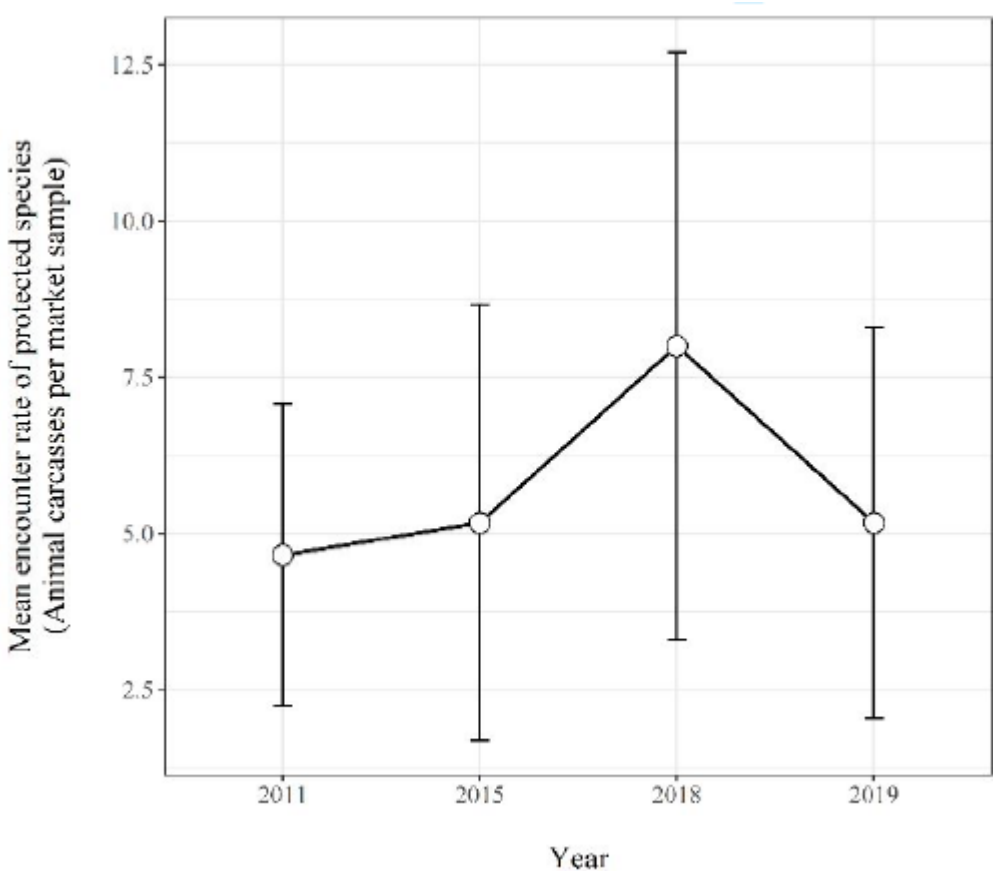


Figure 4. Mean encounter rate (by year) of protected animal carcasses (per market sample) in bushmeat markets in North Sulawesi in 2011, 2015, 2018 and 2019. Error bars represent the standard error of the mean.

3.3. Objective 3: Seasonality, market and price

After accounting for differences in survey effort, the encounter rate of bushmeat observed for sale changed significantly by month (LRT; $\chi2(9)=153.995$, $p<0.001$). As shown in figure 5, a peak in May/June and a trough in October was observed, with encounter rates generally higher between November and June than between July and October. Smaller peaks were observed in March and November (Fig. 5). These peaks broadly align with the celebration period of Thanksgiving, and to a lesser extent with the run-up to Christmas and Easter. The monthly encounter rates of protected taxa showed a similar pattern (LRT; $\chi2(9)=59.076$, $p<0.001$), with noticeable peaks in June and November; however the relatively small sample size meant that these data were patchily distributed across months and this result should be treated with caution.

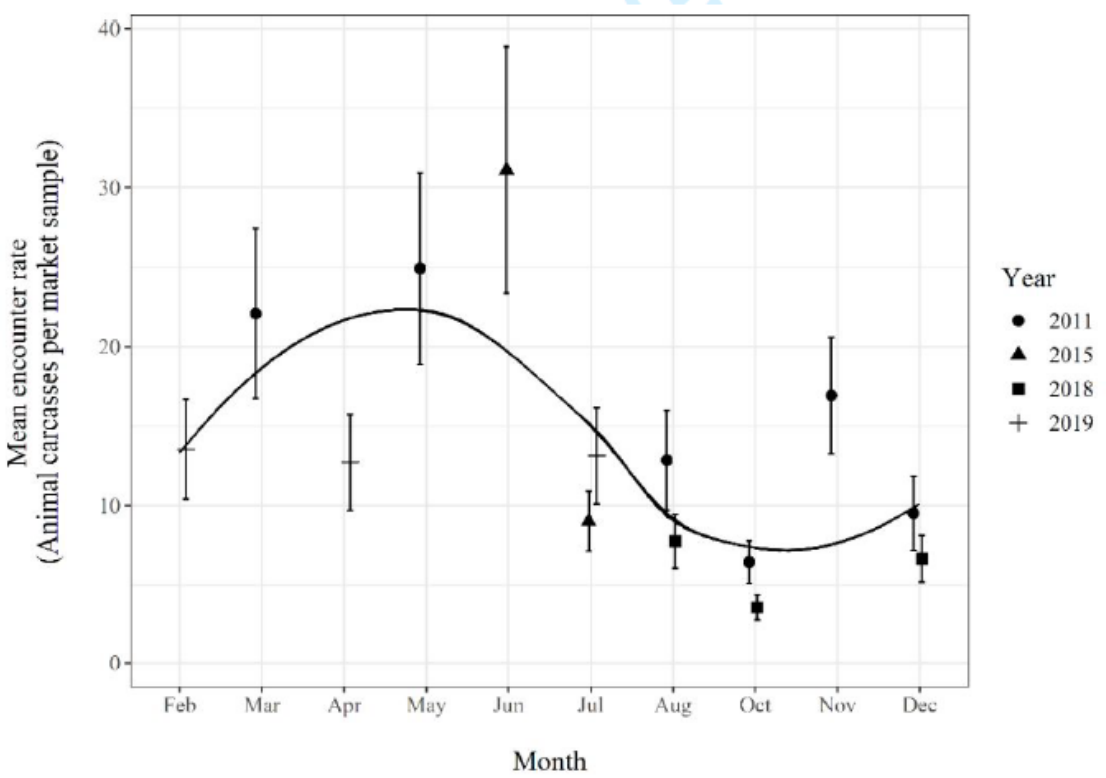


Figure 5. Mean encounter rate (by month and year) of animal carcasses (per market sample) in bushmeat markets in North Sulawesi in 2011, 2015, 2018 and 2019. As indicated by the figure key, different months were surveyed in different years. The trend line is included as a visual aid, not a statistical interpretation of the data. Error bars represent the standard error of the mean.

After accounting for differences in survey effort, the encounter rate of bushmeat observed per market sample differed significantly by market and year (Interaction between market and year LRT; $\chi2(18)=46.587$, $p<0.001$). Encounter rates at Motoling and Tomohon were significantly higher than at Kawangkoan, Airmadidi and Amurang in all years (Fig. 6). Although encounter rates changed between years, markets consistently sold similar proportions of bushmeat relative to each other. The encounter rate of protected taxa observed per market sample also differed significantly by market (LRT; $\chi2(6)=34.023$, $p<0.001$). The highest encounter rates for protected taxa were at Motoling, followed by Ibolian, and Tomohon. Encounter rates were lowest in Amurang and Kawangkoan.

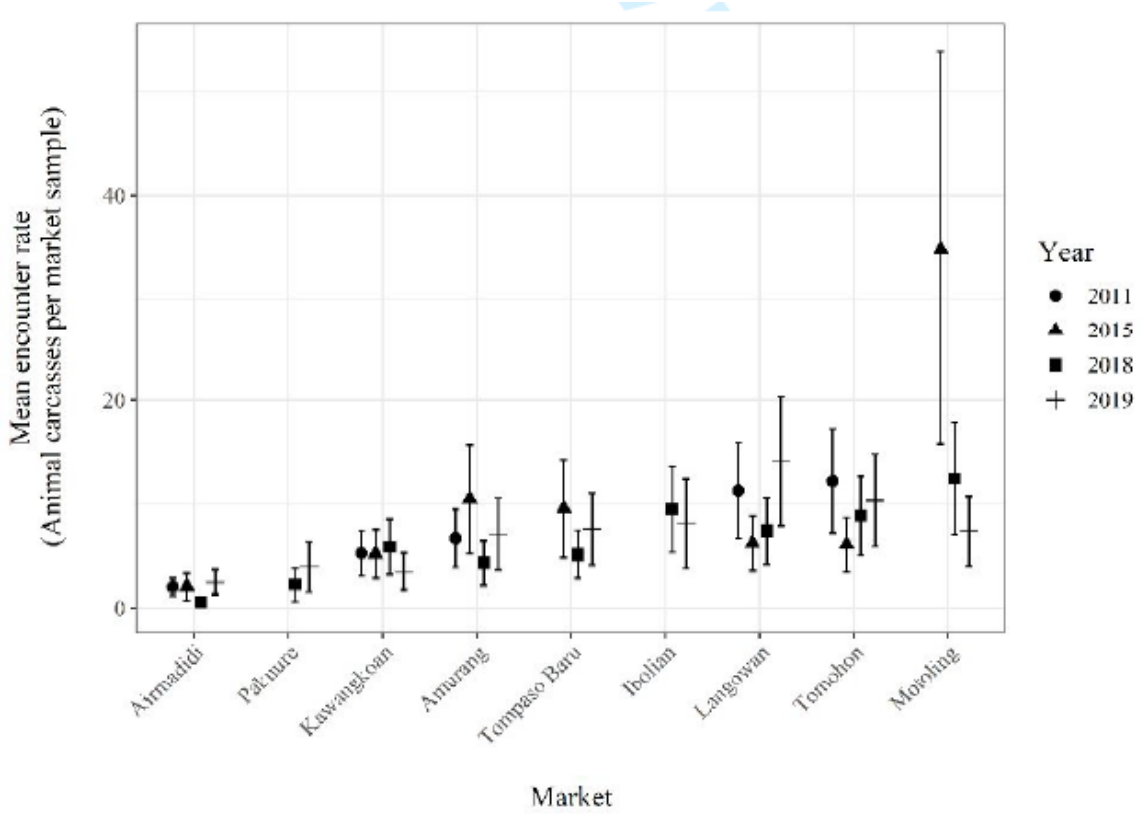


Figure 6. Mean encounter rate (by market) of animal carcasses (per market sample) observed for sale in bushmeat markets in North Sulawesi in 2011, 2015, 2018 and 2019. Error bars represent the standard error of the mean.

Overall, bushmeat price per kg increased significantly and consistently from 2011 to 2019 (LRT; $\chi2(3)=279.5$, $p<0.001$). When examined separately the mean price of protected taxa also increased across the study period, but post-hoc testing did not identify any statistically significant difference in price per kg between years. However, this may reflect the relatively small sample size of protected taxa, rather than the absence of any price increase over time.

4. Discussion

This study documents longitudinal trends in the bushmeat market trade in North Sulawesi for the first time. The study shows an overall decrease in bushmeat observed for sale between 2011 and 2019, with no significant change in the encounter rate of protected taxa carcasses observed for sale over the same period.

Trends in bushmeat observed for sale:

One explanation for the decline in bushmeat observed for sale is that demand has decreased, perhaps because of successful awareness-raising campaigns or a shift in consumer behaviour away from more traditional markets (due to investment and urbanization in the region). In the past decade, North Sulawesi has seen significant conservation efforts aimed at shifting consumer awareness, attitudes and consumption, with NGO-led programmes working to reduce the hunting of protected taxa and to promote environmental conservation (e.g., the Yaki Pride campaign in North Sulawesi). These campaigns focused on protected taxa but included broad messages such as health warnings that are applicable to all bushmeat. As such, it is possible that conservation efforts may have resulted in a reduction in demand for wild meat more broadly. Decreased demand could also be linked to wider societal and economic changes; Indonesia's economy has continued to grow during the last decade, with Sulawesi maintaining economic growth in all regions (Panggabean, 2016; Bank of Indonesia, 2019). Increases in GDP per capita, reduction in poverty and

unemployment in Sulawesi and a 600% increase in tourism to North Sulawesi between 2015 and 2018 (Parassa et al, 2020) may have contributed to reduced demand for bushmeat and changes in consumer behaviour, as more consumers move away from rural market areas to urban areas of national industrial investment and tourism such as Bitung and Manado (Adhima, 2019; Morse, 2019).

The decline in bushmeat observed for sale over this period may also be attributable to a reduction in supply; possibly due to a decrease in hunting, a decline in wildlife available to hunt, or both (McNamara et al., 2016). Increased law enforcement and patrols in protected areas have the potential to deter hunting, leading to reduced supply to markets over time (Lee, 2005). However, studies of hunters in Sulawesi indicate that law enforcement is not a deterrent at its current intensity (Lee, 2005, Rejeki, 2018). Hunting activities may also have reduced over time as opportunities in other economic sectors such as tourism and industry have grown. Alternatively, there may simply be less wildlife available to hunt. Lowland forests in Sulawesi have been increasingly depleted by resource1 extraction and agriculture (Margono et al., 2014), with an annual deforestation rate of 2.7% of total forest area (Rijal et al, 2019). Although current population data are unavailable, populations of 70% of the taxa identified to a species level during this study are decreasing according to the IUCN Red List. A combination of habitat loss and hunting pressure could therefore have contributed to a decline in wildlife availability, which would be reflected in market sales. Patrols and surveys on trade routes have confirmed that bushmeat, including large numbers of bats and Sulawesi warty pigs, are imported into North Sulawesi from other regions in Sulawesi for trade at markets (Sheherazade & Tsang, 2015; Rejeki, 2018; Latinne et al., 2020). Indonesian wildlife has been identified as highly vulnerable to unsustainable harvesting (Di Minin et al., 2019), and this practice could result in source populations around Sulawesi being too depleted to support the bushmeat trade.

A final possible explanation for the decline in bushmeat observed for sale is that trade may have shifted from the markets that we sampled, with bushmeat now being sold elsewhere. This could be due to law enforcement in the markets, improved transportation routes in the area or sales moving to a different setting, such as homes, other meeting places, or potentially online. There is a well-documented online trade in wildlife sold as pets in Indonesia (Siriwat & Nijman, 2020; Morcatty et al., 2021) but no published data on whether similar online marketplaces exist for wildlife sold as bushmeat. There is no evidence to suggest that the trade has shifted location, but further research is needed to explore these possibilities.

Protected taxa observed in the markets:

The proportion of bushmeat observed for sale that was identified as a protected species was consistently low compared to non-protected taxa, and there was no significant difference in price between protected and non-protected taxa. These results support the findings of other research indicating that these protected taxa may be opportunistically caught and sold rather than specifically targeted (Clayton & Milner-Gulland, 2000; Branch, Lobo, & Purcell, 2013; Rejeki, 2018). This may also explain why their encounter rate remained stable over the study period rather than declining in line with the wider encounter rate. That protected taxa were consistently found in markets at relatively similar levels each year could also indicate a continued, low-level demand, on which conservation actions and law enforcement had limited impact. However, these results should be treated with caution as the protected taxa sample size in this study may have been too small to reveal a significant trend.

17 *Seasonality, location, and price:*

The encounter rate of animal carcasses observed for sale was significantly different between months in all survey years. Our findings do not demonstrate clear peaks during festive periods. The

results do indicate that consistently more bushmeat is sold in the months between November and July, and that sales of protected taxa seem to peak in June and November. More bushmeat was consistently observed in Tomohon, Motoling, Langowan and Ibolian markets, compared to other markets during the study period and this effect of location warrants further investigation. These markets are located near or within the larger towns in the area, and may have higher demand. The observed increase in price of all bushmeat is an expected result of inflation between 2011 and According to the IMF, the inflation rate has slowed between 2011 (5.3%) and 2019 (2.9%), which broadly correlates with our results.

Limitations and further research:
Taken together the results of this study offer valuable insights into the bushmeat trade in North Sulawesi. However, when evaluating our findings and planning similar field assessments, severallimitations should be acknowledged, both in our approach specifically, and in this methodological approach more generally. Three key points should be considered: First, different surveyors were used in most years, which could have affected the counts and species identification. Any variation is likely minimal as surveyors were trained prior to data collection and given a simple and standardised method to follow, and future studies would benefit from either retaining the same surveyors (difficult for work that occurs over a long period of time) and/or ensuring that all surveyors are trained to the same high standard. Second, markets were not evenly sampled within or between years. Although the appropriate analytical approach (i.e., modelling encounter rates rather than counts) can compensate for this, the extent of the bushmeat trade may be better represented by starting future work with a more even sampling regimen. Finally, due to the illegal nature of some bushmeat trade it can be challenging to identify and quantify the hidden trade in protected animals not sold openly in markets. Indeed, during our market surveys there were indications that some protected taxa were sold privately from vehicles outside the markets (pers. obs. Lawe). Future studies would benefit from taking a more sensitive approach to this issue, as demonstrated by Razafimanahaka et al.'s (2012) randomized response technique that encourages honest reporting of illicit activities without fear of identification or recrimination on the part of the respondent.

More broadly, the information that longitudinal, quantitative studies provide is best used as part of a wider conservation strategy, e.g., by quantifying market trade over the course of long-term conservation action. Longitudinal market surveys, in combination with social data collection such as interviews with hunters and consumers, can further our understanding of which strategy to pursue, and evaluate the impact of that strategy. Ultimately, population monitoring is needed to quantify the impact of the market trade on wildlife, but this approach should also take place within a wider framework that includes longitudinal market surveys, interview data, and the identification of trade routes and harvesting locations. Selamatkan Yaki is currently collecting and analysing complementary qualitative data to provide a more comprehensive overview of the bushmeat trade in North Sulawesi. This kind of research may be particularly illuminating given the current COVID-19 pandemic, whose origins have putatively been linked to bushmeat markets (Andersen et al., 2020; McNamara et al. 2020). Based on our current findings, further research is also recommended to discover the breadth of the trade not openly displayed at markets. More regular and frequent bushmeat surveys are also necessary to obtain more detailed information regarding seasonal trends. This information could be used to identify specific periods of high demand and more accurately inform conservation efforts.

Conservation recommendations:
Although our study cannot demonstrate whether hunting for bushmeat in North Sulawesi is sustainable, other research indicates that this is not the case, at least for certain species (e.g., bats; Latinne et al. 2020). Despite the encounter rate of protected taxa observed in the markets remaining

low, our results indicate that the proportion of protected taxa observed has not decreased in line with the overall bushmeat trade over the study period, which could indicate a persistent (if small) demand for threatened endemic taxa in Sulawesi. Conservation interventions have been widely recommended to mitigate the bushmeat trade in North Sulawesi (Clayton & Milner-Gulland, 2000; O'Brien & Kinnaird, 2000; Lee et al., 2005; Sheherazade & Tsang, 2015; Gray et al., 2018; Rejeki, 2018; Latinne et al., 2020), and tackling the bushmeat trade demands a multi-faceted approach due to its complexity and the diversity of stakeholders involved (Crookes & Milner-Gulland, 2006; Challender, Harrop, & MacMillan, 2015). A strategy to mitigate bushmeat trade in North Sulawesi therefore must consider and involve all stakeholders in order to be effective. We recommend the following conservation interventions: improving the efficiency of law enforcement in parallel with intensive education and awareness-raising campaigns; introducing and implementing data-driven hunting quotas for all legally traded taxa; and developing behaviour change strategies to reduce the demand for bushmeat where necessary.

5. Conclusion

Although the downward trend in encounter rate of bushmeat since 2011 could indicate reduced hunting, the high number of animals still for sale, and the reported importation of animals from other regions to supply North Sulawesi markets suggests that this trade remains a potential threat to biodiversity in the region, including protected taxa. We have offered several possible explanations for the changes in bushmeat observed for sale, however, the complexity of the issue means that drivers of the bushmeat trade cannot be easily isolated. Further research, that places bushmeat hunting and consumption in its social, economic, cultural, and psychological context, is required to identify the underlying drivers of the observed reduction in the bushmeat trade and to establish its ultimate effect on wildlife populations. This is strongly recommended to put our results and future market surveys in context for threatened taxa in this important centre of biological endemism.

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