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RESEARCH ARTICLE

The role of the introduced rusa deer *Cervus timorensis* for wildlife hunting in West Papua, Indonesia

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Abstract

1. The rusa deer has been introduced to Merauke region and later to Vogelkop Peninsula in Indonesian New Guinea (West Papua) in 1928. It has widely dispersed across much of the West Papuan lowlands, but little is known on population size and its role for the livelihoods of rural communities. Here, our aim was to assess the population status of rusa deer, and to investigate the extent of hunting practices on this mammal in West Papua.
2. We conducted camera trapping and line transect surveys simultaneously to estimate rusa deer population abundance in the Kwoor basin of the Tambrauw regency, Papua Barat province, Indonesia. We also interviewed hunters ($n = 134$), informants ($n = 9$) and households ($n = 91$) to assess hunting patterns and socioeconomic importance of rusa deer across 15 districts of the Tambrauw regency.
3. We estimated rusa deer density within a 48-km^2 forested area at 10.34 (5.36–19.98) and 21.04 individuals/km^2 using line transect and *N*-mixture modelling approach using camera trapping data, respectively. Both density estimates are considerably higher than those from its native range in Java and Bali (0.08 individual/km^2). Almost 92% of hunters reported that they hunted rusa deer in their traditional forests, being the most frequent amongst the 18 hunted species, particularly for commercial (62%) and subsistence (38%) purposes.
4. Our results suggest that traditional hunting has become a significant livelihood activity and important income source in the study area. It is therefore imperative to identify potential management strategies on wildlife hunting while also considering that the high densities of introduced rusa deer may potentially exert adverse effects on native flora and fauna.
5. This study further suggests that traditional knowledge (locally called 'sasi' system) and wildlife taboos still govern wildlife hunting and utilization of forest resources in West Papua, and these need to play a role in integrated community-based wildlife management.

KEYWORDS
Indonesian New Guinea, invasive species, population abundance, rusa deer, sasi system, socioeconomic, sustainable management, wildlife hunting

1 | INTRODUCTION

Human-mediated movement of mammals ensued a variety of reasons such as food, domestic stock, hunting and sport, fur industry and bio control (Long, 2003; Parkes & Murphy, 2003). For example, various species of deer have been introduced to countries around the world for hunting purposes, but in some cases they have become overabundant, which had harmful consequences for the native vegetation (Davis et al., 2016; Parkes & Murphy, 2003).

The Javan rusa deer (*Cervus timorensis*Blainville, 1822) (hereafter 'rusa deer') is a medium-sized (shoulder height up to 110 cm) deer native to the islands of Java and Bali in Indonesia (Corbet & Hill, 1992). It occurs in pairs or small groups (Long, 2003), but the males are also found solitary. Ecologically, the rusa deer is adapted to tropical and subtropical grassland ecosystems (Oka, 1998), and show high adaptability to forests, mountains, shrublands and marshlands (Keith & Pellow, 2005). The rusa deer has been introduced to various regions around the world, including Indonesian New Guinea (hereafter 'West Papua') (Hedges et al., 2015), presumably for meat consumption. The species was initially introduced into the Merauke region in 1928, and later to Vogelkop Peninsula (Flannery, 1995; Brodie et al., 2018). Since then, the species has widely dispersed across the West Papuan lowlands (Flannery, 1995). Now, the rusa deer is common in much of its current distribution range (Corbet & Hill, 1992; Moriarty, 2004), but less so in its native range, where its population had markedly declined by ~10,000 individuals over two decades (Hedges et al., 2015), and is seemingly still facing further decline (Semiadi, 2006; Hedges et al., 2015). It is therefore listed as 'vulnerable' in its native range (Hedges et al., 2015), and has been officially protected by Indonesian law since 2018 (Indonesian Ministry of Environment & Forestry, 2018). However, the largest portion of its populations reportedly occurs outside its native range, including New Caledonia with ~120,000 individuals (Desvals et al., 1992) and Mauritius with about 60,000 individuals (Hedges et al., 2015). For West Papua's Wasur National Park alone, 8000 individuals were estimated in 1992 (Hedges et al., 2015). The corresponding density estimate for this 4138-km^2 park would be 1.93 individuals/km^2. If that density was representative for the forested areas of West Papua (340,436 km^2; BPS Indonesia, 2021), an estimate of about 658,000 individuals of rusa deer for West Papua as a whole could be made.

The introduction of mammals to the island of New Guinea is of special conservation concern, because the region historically lacks placental lineages, and increased abundance of the introduced/invasive mammalian species (e.g. rusa deer, wild pig) can adversely affect the native flora and fauna in this region (Brodie & Pangau-Adam, 2016). In this way, also the rusa deer might become a competitor and threat to native marsupial herbivores. For example, in Papua's Nimbokrang forest the detection of rusa deer was approximately two times higher than that of the native white-striped dorcopsis (*Dorcopsis hageni*), which has a relatively similar feeding ecology (Brodie et al., unpublished data). Bowe et al. (2007) reported that in south-western Papua New Guinea (hereafter 'PNG') and West Papua the grazing pressure of rusa deer can lead to large-scale damages to swamps and grasslands, particularly to the disappearance of some native grass species (*Phragmites* spp.). In New Zealand and several federal states in Australia, to reduce population abundance of introduced deer species, public and game hunting approaches have been implemented, but these may be successful only at small scales, and complete eradication may only be possible in isolated populations (Parkes & Murphy, 2003; Davis et al., 2016). However, not all introduced and invasive animals are considered as pests, because in some regions they might function as food resources (Latham et al., 2017). This is also the case with the rusa deer, whose meat is supporting livelihoods of the indigenous people of West Papua (Pangau-Adam et al., 2012; Pattiselanno et al., 2020). Therefore, both, mitigating unwanted impacts on forest ecosystems and maintenance of a resource value, could potentially be combined in a sound management approach (Telfer, 1997; Latham et al., 2017).

In West Papua, wildlife has played a significant role both in the livelihood and culture of indigenous people (Pangau-Adam & Noske, 2010). Moreover, the transmigrant communities and non-Papuan ethnic groups often rely on wildlife hunting for various purposes. A number of large-sized mammals and birds including rusa deer are primary target species for hunting in PNG and West Papua (Johnson et al., 2004; Pangau-Adam et al., 2012). In order to regulate the sustainable use of wildlife for subsistence and commercial purposes, it is necessary to design and implement wildlife management plans (Robinson & Bennett, 2000). The rusa deer potentially offers opportunities to support sustainable economic developments in rural areas in West Papua (Pattiselanno et al., 2020). Moreover, managing its populations may also have the potential to reduce hunting pressure on native fauna such as marsupials and ground-dwelling birds.

Despite awareness raising by conservationists and environmental groups about introduced animals and wildlife hunting in West Papua, there are limited studies addressing hunting patterns and their sustainability in this region. Assessing the basic population status of rusa deer in West Papua is therefore an important aspect to evaluate its ecological as well as its socioeconomic role. The specific objectives of this study were (i) to assess its population density and abundance, (ii) to determine its role for the livelihood of local people and (iii) to document wildlife hunting patterns in general.

2 | MATERIALS AND METHODS

2.1 | Study area

Our study site is located in the Tambrauw regency, in the northern part of Vogelkop Peninsula, Papua Barat province, Indonesia. The regency covers an area of 11,592.18 km^2, and consists of 29 districts. It has been designated as a conservation regency by the Tambrauw government. Over 80% of the Tambrauw land surface have been set aside as conservation areas and protected forests (BAPPEDA Tambrauw, 2014). The West Papua forests in the alluvial plains host high species richness, particularly high numbers of tree species (Petocz, 1989). In 2010, the Tambrauw regency had a small estimated human population of ~6144 inhabitants (0.53 individual/km^2). In 2019, however, due to immigration from other regencies and an improved census of human population in isolated areas, the population estimate has increased, and is now at ~28,379 people (2.45 individual/km^2) (BPS Sorong, 2021). There are six local tribes, namely Abun, Miyah, Ireres, Mpur, Biak Karon and Moi Kelin distributed over 216 villages in the Tambrauw regency. The first four tribes are from the original Tambrauw population, while the two latter are belonging to the Biak island and other coastal areas in the Vogelkop Peninsula. In 2015, this regency had only 78 villages, but numbers increased up to 216 villages in 2019 (BPS Sorong, 2021). However, several villages were now found empty as the inhabitants temporarily moved to get access to the markets in towns and cities (personal observation).

2.2 | Study design

We conducted our study from May to October 2019, that is mainly during the dry season. In West Papua, the dry season extends from May to September and the wet season ranges from October to April. However, recently the climate became less predictable, with temperatures ranging from 24 to 32°C and average humidity being approximately 84%–90% (BPS Papua Barat, 2021). The population estimation of the rusa deer was conducted in the Kwoor basin, covering an area of 48 km^2. We carried out our interview surveys across 15 districts of the Tambrauw regency (Figure 1). We superimposed a grid of 2 × 2 km cells in the study area, each cell including one or two transects with a random starting point (Figure 1). The transect lines were randomly distributed across grid cells and were spaced at least with 1 km distance. We implemented the transect surveys by two teams, each composed of three observers, one researcher and two skilled indigenous people, who were able to unambiguously identify and detect the rusa deer.

2.3 | Distance sampling

Along each transect, we measured the detection distances (r) and angles (θ) from the line to animals using a laser range finder (Leica1000-R) and a GPS (Garmin 64s). The perpendicular distances ($x_i, \ldots, x_n$) were then calculated as $x = r \sin \theta$ (Buckland et al., 2001; Thomas et al., 2010). The frequency distributions of perpendicular distances were used to calculate the probability density function $f(x)$ that models the reduction in detection of rusa deer groups with distance from the line. We defined the cluster as a group of rusa deer detected together in a single detection event along the transects. The cluster density was estimated by the 'ds' function (Miller, 2019) using transect-specific encounter rate (ER; can be obtained by the ratio of number of cluster observations per kilometre of transect surveyed [n/L]). We estimated the detection probability $g(x_i)$ as a function of observation distances (Buckland et al., 2001; Buckland et al., 2015). Abundance estimates for a survey region can be calculated as $A \times N/a$ where A is the survey region and N is the abundance in the covered (sampled) region (Miller, 2019). To estimate the abundance ($\widehat{N}_C$) in the entire study area, first, the abundance in our sampled area was measured by the Horvitz–Thompson-like estimator:

$$\widehat{N}_C = \sum_{i=1}^{n} \frac{s_i}{\hat{p}(z_i)},$$

where $\hat{p}(z_i)$ ($i = 1, \ldots, n$) is the detection probability estimate and s_i are the sizes of observed rusa deer groups (Borchers & Burnham, 2004; Miller, 2019). We then extended up to our sampled study area by

$$\hat{N} = \frac{A}{a}\hat{N}_C,$$

where A is the area of the study region and a is the sampled area which was measured as $a = 2wL$, which is twice the truncation distance multiplied by the total length of transects (L) (Buckland et al., 2001; Miller, 2019). We ran several distance models using the 'ds' function in R package 'Distance' (Miller, 2019). Three key functions were used including the half-normal with default 2 cosine adjustment terms, a hazard-rate and a uniform key function with 1 and 2 cosine adjustments. The detection function models were only fitted for the pooled rusa deer data without stratification of the area. However, we fitted multiple covariates in our distance models such as normalized vegetation difference index (NDVI), the mean elevation and the observers as factor. The NDVI was derived from Landsat-8 images and measured by taking the ratio of red (R) and near infrared (NIR) values as (NIR − R) / (NIR + 1) (https://earthexplorer.usgs.gov/). A truncation distance of >47 m was selected for all the models to retain a large portion of the observations. To assess goodness-of-fit of the models, we used the Cramér–von Mises test, which compares the cumulative distribution function and empirical distribution function (Buckland et al., 2001; Thomas et al., 2010; Miller, 2019). We used Akaike's Information Criterion (AIC) to select best fitted models (Burnham & Anderson, 2002; Buckland et al., 2015).

2.4 | Camera trap surveys

In May 2019, we deployed 23 Reconyx HC500 camera traps at the start and end points of the randomly distributed line transects, with camera traps being spaced at least with ~1 km distance (Figure 1). The cameras were placed within protective metal cases and mounted to the

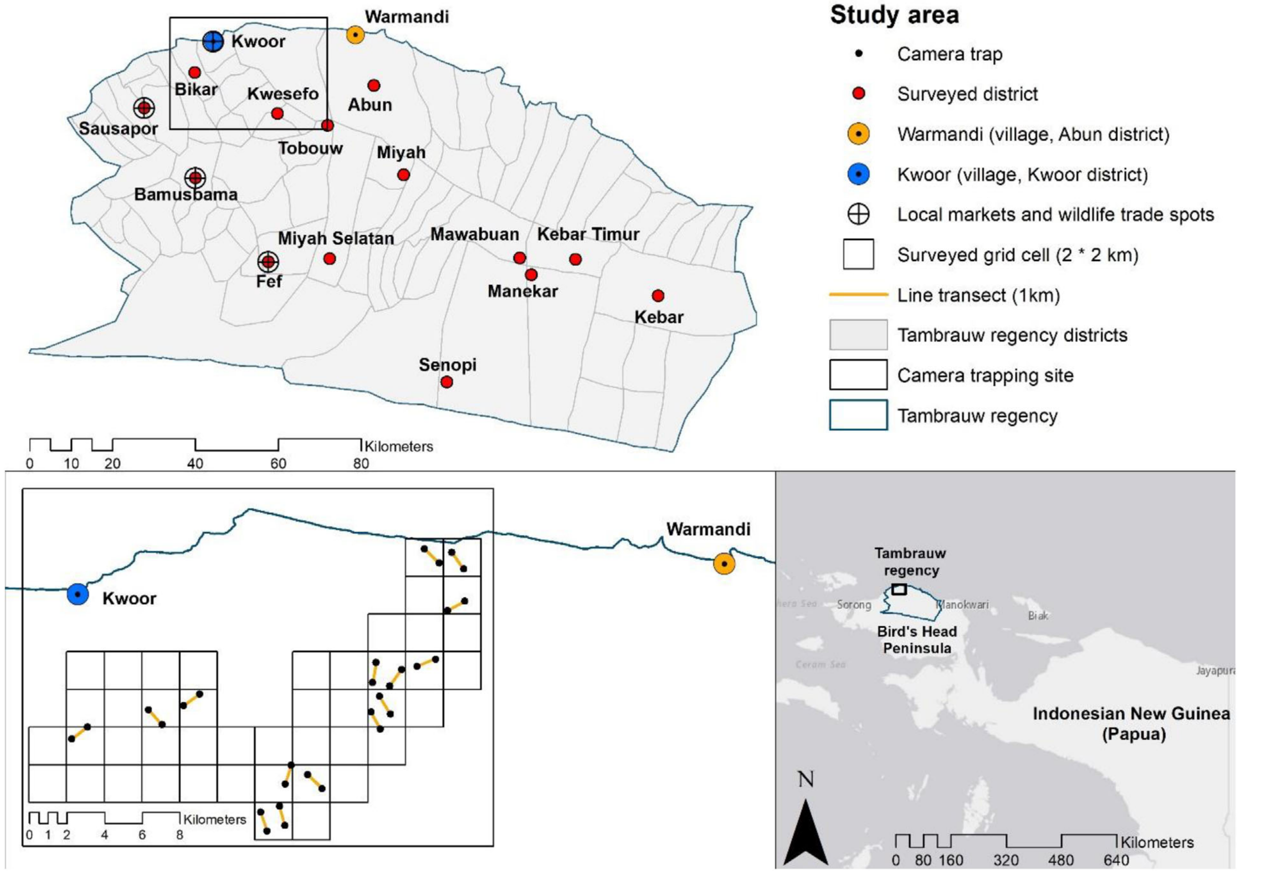

FIGURE 1 Map of the study area in the Tambrauw regency, Papua Barat province, Indonesia

bases of the trees at ∼50 cm above the ground (Soofi et al., 2017), a height suitable to capture rusa deer. Overall, the camera traps were operated about 6 months with a total of 3289 camera days across 23 sites. Within that period, two camera traps were lost and three failed to operate, which resulted into 2309 camera days, and the detection of 1349 individuals of rusa deer or 0.58 individuals/camera day. We defined the period of a single sampling occasion as 2 weeks (MacKenzie et al., 2018), representing replicated counts (Royle, 2004) of rusa deer obtained from camera trap operations. Thus, count data were replicated over 11 occasions (i.e. between May and October). We measured the mean distance from the camera stations to the nearest villages and the rivers for each cell. Overall, we calculated two sets of covariates for each sampling unit: (1) site covariates included 'distance to village' (i.e. a distance from camera trap location to the nearest village), distance to river, elevation and normalized difference vegetation index (NDVI), and (2) observation covariates included 'trapping efforts' (i.e. the number of days that each camera trap has been operated over the entire camera trapping period). Moreover, to estimate expected abundance of rusa deer, we applied a single-season *N*-mixture model. An approach developed by Royle (2004) is to estimate expected animal population without the need for recognition of animals at individual levels. We fitted two different *N*-mixture models, namely a negative binomial and a Poisson mixture model (Royle, 2004; Kèry & Royle, 2016). We first fitted models with linear effects of covariates (i.e. elevation, distance to village, distance to river) on detection probability '*p*', while we kept the abundance model constant. Then, we kept at least one covariate in the detection model while we modelled variables on abundance '*N*'. Furthermore, we combined the covariate effects on both parameters (Kèry & Royle, 2016). Then, we selected best fitted models based on the quasi-Akaike Information Criterion (QAIC; Burnham & Anderson, 2002) using the 'AICcmodavg' R package (Mazerolle, 2019). Finally, we ran a bootstrap goodness-of-fit analysis with 1000 iterations and fitstats function (Kèry & Royle, 2020). We considered the effect size as significant if the 95% (CI) of the mean coefficient did not include zero (Kèry & Royle, 2016).

2.5 | Interview surveys

We implemented focused group meetings and interview surveys using semi-structured questionnaires. The questionnaires were focused on hunting reasons, hunting tools, frequency of hunting trips, hunting ground and the target species. We conducted interview surveys with hunters (n = 134), village leaders (hereafter 'informants') (n = 9) and households (n = 91) in 25 local villages of 15 districts in Tambrauw (Figure 1). The location of the villages ranged from nearby towns, riversides, coastal belts, highland areas to the distant forests with limited road access. Besides the existence of leadership at each village, there is

TABLE 1 Summary for the distance models performed to assess rusa deer distance data in Kwoor basin, West Papua

Region	Area (km^2)	Sample Area (km^2)	Encounter rate in clusters per km (SE)	Expected cluster size (SE)	Model	Goodness-of-fit: Cramér–von Mises test	Goodness-of-fit: p-value	Goodness-of-fit: df	Abundance (0.95% CI)	Density, km^{-2} (95% CI)	CV%
Kwoor	48	2.65	0.60 (0.15)	2.35 (0.12)	Half-normal cosine, adjustment 2	0.19	0.29	29	497 (257–959)	10.34 (5.36–19.98)	33
					Hazard-rate cosine + habitat	0.15	0.39	27	461 (237–893)	9.60 (4.96–18.60)	33
					Uniform cosine, adjustment 1, 2	0.14	0.41	18	449 (166–1219)	9.36 (3.45–25.40)	51

Note: Estimates of abundance and density from the observed rusa deer groups, and the encounter rates (group km^{-1}) are presented.
Abbreviations: CI, confidence interval; CV, coefficient of variance; df, degree of freedom

a traditional/tribal institution consisting of several clans (locally called 'marga'), which regulates the use of traditional forest or 'Hutan adat'. Currently, due to rapid regional development in Papua, the villagers living along the coastal areas and nearby towns have mingled with other West Papuan ethnic groups from Biak, Serui, Ayamaru, Arfak and Fakfak, as well as non-Papuan people from Makassar, Bugis, Buton Island, Java and Mollucas (Pattiselanno et al., 2020). The informants are village leaders, who informed us that they stopped to hunt animals and they provided information related to wildlife hunting. Prior to the interview surveys, we discussed our study goals with villagers, tribe and clan leaders to get permission and obtain information on hunting activities. We also surveyed the local markets in Sausapor and Fef districts and wildlife trade spots in Kwoor and Bamusbama districts (Figure 1), and obtained information pertaining to hunted wildlife particularly rusa deer trade. Wildlife trade spots are smaller than local markets and primarily offer wildlife meat and living birds. To compare the mean differences in proportions of wild animals in the meals reported by households, we applied a Tukey's honest significant difference test using the 'nparcomp' R package (Konietschke et al., 2019).

3 | RESULTS

Our foot surveys along 15 transects (30.2 km of effort) led to 21 independent observations of 48 rusa deer (the mean cluster size with excluding solitary rusa deer = 2.86 ± 0.25 standard error [*SE*]). Of which, only two individuals were male. The cluster size of the rusa deer ranged between one to four individuals and five solitary rusa deer. The mean cluster size including the solitary deer was 2.29 ± 0.22 *SE*. The mean encounter rate of rusa deer cluster size per km was 0.60 ± 0.15 *SE*, and the mean expected cluster size after truncation was estimated at 2.35 ± 0.12 *SE*. The mean density in the covered area for the top model with the lowest ΔAIC was 27.42 ± 7.29 *SE* individual/km^2 with a coefficient of variance of CV% = 27. The effective strip-width estimated for the observed counts was 23 m. The half-normal cosine function appeared as the top model but the hazard-rate cosine with habitat as covariate and the uniform with 1 or 2 cosine adjustment terms showed nearly similar estimates (Table 1). The habitat covariate in the hazard-rate model revealed that transects located around the river system negatively affected detections of rusa deer (−0.34 ± 0.58 *SE*). Density in our best model was estimated at 10.34 individuals/km^2 (95% CI = 5.36–19.98) and average abundance at 497 (95% CI = 257–959) individuals for the 48-km^2 study area.

The goodness of fit (GoF) tests of all distance sampling models showed insignificant Cramér–von Mises statistics, and we, therefore, regarded them as plausible models (Table 2). The half normal and hazard rate models showed satisfactory CVs. By comparison, however, the uniform cosine model revealed a relatively wider confidence interval both in abundance and density estimates with a fairly larger CV% = 51 (Table 1). The detection probability against observed distances showed a variability in observations with a fall-off in probability of detection with distance from the line. The detection probability was higher (p = 0.6–1.00) between 0 and 23 m distances, but at $p > 0.56$ halved after 23 m distance, where we had only few observations (n = 3).

3.1 | Camera trap survey (*N*-mixture model)

We found that the negative binomial (NB) model was the best fit. The population abundance of rusa deer under NB model was estimated to be 1010 (95% CI 814–1243; 21.04 individual/km^2). However, the Poisson mixture model did not pass the GoF-test. Our NB model estimated elevation to be positively (β = 0.87, CI = 0.32–1.41) linked to abundance of rusa deer (Table 3). Also, increasing distance from villages had a positive effect on detection probability (β = 0.37, CI = 0.16–0.59). Likewise, detection probability (β = 0.51, CI = 0.35–0.69) was also affected positively by camera effort.

We found that the detection of rusa deer was higher in July and August (dry season) than in other months. The covariates in the best Poisson model showed that rusa deer abundance increased significantly with increasing distance from villages (β = 0.57, CI = 0.47–0.67), and also with elevation (β = 0.44, CI = 0.34–0.53) (Table 3). Both the Poisson and the negative binomial model indicated a high population abundance of rusa deer in the study sites. These results partially

TABLE 2 Summary of the detection function models fitted for rusa deer distance data

Model	Key function	C-vM *p*-value	($\hat{P}_a$)	se($\hat{P}_a$)	ΔAIC
1	Half-normal cosine, adjustment 2	0.29	0.62	0.14	0.00
2	Hazard-rate cosine + habitat	0.39	0.67	0.13	0.80
3	Uniform with cosine adjustments 1, 2	0.41	0.69	0.31	0.86

Note: C-vM stands for Cramér–von Mises test statistic, $\hat{P}_a$ is average detectability, and se is standard error. Models are selected according to Akaike's Information Criterion (AIC). Truncation width $w = 47$ m in all cases.

TABLE 3 Parameters estimates of negative binomial (NB) and Poisson (P) abundance model and AIC for rusa deer camera trap count data, in West Papua, Indonesia, during May–October 2019

	Abundance (lambda)		Detection (*p*)				
Model	*k*	β_0	β_{elev}	α_0	$\alpha_{disvilg}$	α_{effort}	AIC
NB	167	3.79 (3.34, 4.23)	0.87 (0.32, 1.41)	−2.38 (−2.63, 2.12)	0.37 (0.16, 0.59)	0.51 (0.35, 0.69)	1073.43
P	167	3.89 (−2.72, 2.08)	0.44 (0.34, 0.53)	−2.40 (3.61, 4.17)	0.57 (0.47, 0.67)	0.62 (0.47, 0.77)	1275.96

Note: The estimates in parentheses indicate the 95% confidence interval. β_0 is the intercept, β_{elev} indicates beta coefficient for elevation, α_0 denotes intercept for detection probability, $\alpha_{disvilg}$ is the distance to village, and AIC indicates Akaike Information Criterion.

overlap with the rusa deer abundance estimate we obtained from the best model in the distance sampling approach. However, our estimated population abundance through *N*-mixture model was greater than the population estimated by the distance sampling technique.

3.2 | Hunting patterns

We found that 18 wildlife species were hunted by local people. Rusa deer and wild pig (*Sus scrofa* × *Sus celebencis*) were the most frequently hunted species in 15 districts with the exception of Bamusbama and Kwesefo districts, where rusa deer was rarely found at high elevations. Approximately, 92% of hunters reported that they have hunted rusa deer in their traditional forests. Animal hunting in the Tambrauw was mainly motivated by subsistence, trade, culture and also to a lesser extent by conflicts over crop raiding. Hunters tended to apply multiple techniques for hunting. Spear (73%), archery (41%), snares (57%) and dogs (68%) were the most prevalent hunting techniques used by local people for rusa deer hunting. Archery, spear and dogs were also commonly used for hunting of wild pig, wallaby and cassowary. Only 9% of hunters used air rifles for hunting of birds, bats and arboreal marsupials. Hunting trips were mostly (92%) pursued alone and in groups with family and clan members. However, group hunting with clan members was only occasionally performed, if there was the need to hunt animals for family or community festivals, or religious and traditional ceremonies. Hunting trips varied from three times per week to two times per month. We found nearly 90% of the hunting trips being practiced by adult men, although school children also searched and hunted wildlife after school time or during school holidays. Hunting activities decreased by 23% during the rainy season, because of heavy rains, flooding and enlarged rivers. Hunters from two districts reported about intensive hunting operations of people from the cities including the participation of the army personals in their clan forests.

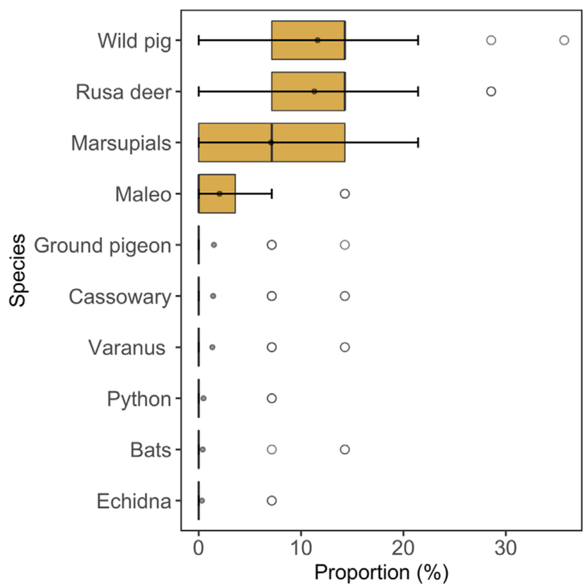

FIGURE 2 Proportion of animals contributed in the meals of local households across 15 districts in Tambrauw regency, Papua Barat province, Indonesia, obtained through interviews during May, July and October 2019. The blank circles indicate outliers and the black dots indicate mean value

The rusa deer and wild pigs were the most consumed animals, but marsupial meat was also frequently consumed by local people. (Figures 2 and S1). Ground birds, bats and reptiles were also part of the diet of surveyed villagers.

3.3 | Commercial hunting and rusa deer trade

We found that rusa deer meat (hereafter 'venison') was sold out at local markets and wildlife trade spots, or collected by handlers (usually immigrant people) from hunter families. The handlers visited the villages at least once a week to mainly seek for venison. The price for venison was about 20,000 IDR (rupiahs) to 30,000 IDR per kg (1 USD = 13,800 IDR), and in the towns/cities the prices ranged from 40,000 to 60,000 IDR per kg of meat. Prices increased during Christmas and Eid feast. Venison was sold at least once a week at the local markets. We found that venison and wild pig meat were sold directly within the villages located far from market towns, and occasionally offered at the roadside of Trans Papua. Our results further showed that many hunters also smoked the venison, which is then called dendeng rusa (i.e. smoked rusa), and brought into the market over the following few days. Finally, the antlers and pelt of rusa deer were traded in towns and cities for home decorations.

3.4 | Sasi system and wildlife taboos

During interview surveys, we found two types of traditional regulations associated to forest and wildlife management implemented by local communities (Table S1). These two regulations are as follows:

1. *Sasi system* (sasi adat dan sasi gereja). Sasi adat is governed by traditional institutions, and sasi gereja (church) is ruled by the Christian church.
2. Wildlife taboos, the traditional beliefs limiting wildlife hunting, for instance taboos of cassowary, hawks, cockatoos, cuscuses and tree kangaroos. Based on these beliefs, whoever hunts the taboo animal will receive punishment in a supernatural form.

4 | DISCUSSION

4.1 | Population status

Our results suggest notable population abundance of the introduced rusa deer in the Tambrauw region, West Papua. We also found that detection probability increased during the dry season (July–August), which is likely to be associated with the breeding season (Hedges et al., 2015) peaking up in this period. We ascribe the comparatively high population density of rusa deer in our study area primarily to the absence of wild predators and the availability of plentiful food resources. The rusa deer population in its native habitat in Java and Bali was reported being ~10,000 individuals (Hedge et al., 2015) within a total predicted suitable habitat of 132,129.5 km^2 (Rahman et al., 2020), representing a much lower density (ca. 0.08 individuals/km^2) than those estimated by us.

The rusa deer tended to avoid river banks, perhaps, because areas near river systems are usually being used by villagers for fishing and other daily activities. As in other parts of West Papua, Tambrauw rivers serve as travel corridors for locals and therefore function as hunting access points (Brodie et al., 2018). Also, rusa deer tended to occupy habitats with a high density of forest vegetation, which potentially provide adequate foraging areas. Our results further showed that rusa deer were significantly more abundant at higher altitudes. Presumably, rough terrain hinders intensive human activity and hence may reduce hunting efforts. However, as reported by villagers and hunters, rusa deer are rarely found in forests at an elevational range of 800–900 m. This is corroborated by Hedges et al. (2015), who also state that rusa deer inhabit landscapes up to 900 m a.s.l.

4.2 | Hunting as a livelihood strategy

We found that traditional hunting is a significant livelihood activity in the Tambrauw region, as it provides the majority of animal protein for the local families. This finding is consistent with previous studies on wildlife hunting in other regions in West Papua (Pangau-Adam et al., 2012; Pattiselanno et al., 2020). In the distant villages, wild meat and/or wild fish were reported as the most frequent protein items in the meals. Hunting on rusa deer was mainly motivated by subsistence, commercial and traditional/religious purposes. These animals (e.g. wild pig and rusa deer) were also hunted in order to reduce crop raiding. In areas where roads to the towns and the marketplaces (i.e. it can take 2 days of walking and 1 day by boat to reach the towns) are rare, wildlife hunting is practiced at subsistence levels to meet the protein needs of families. Prior to arrival of westerners in the early 1900s, local people in this region have hunted wildlife only for subsistence purposes (Pangau-Adam et al., 2012). The introduction of a cash market economy, combined with rapid urban and infrastructure developments in the Tambrauw regency, has brought a significant change in hunting purposes and practices in this region. Approximately 62% of the interviewed hunters declared that they hunt for commercial purposes, suggesting that there has been a marked shift from local-level subsistence hunting (38%) for meat consumption towards more intensive commercial hunting.

Multiple hunting techniques are being employed by local people to hunt a variety of wildlife species including rusa deer. Most of the hunters (90%) reported that they apply more than one technique for hunting. Snares were used to capture rusa deer and wild pigs, but other non-targeted native wildlife species such as cassowaries, crowned pigeons, brush turkeys, echidna and ground marsupials can also be trapped upon encounters. The rusa deer and wild pigs seem to be targeted for commercial hunting purposes. These species are a relatively easy target for hunting compared to other animals, because they tend to use trails in the forest along which hunters often set up snares to capture them (Pangau-Adam et al., 2012). Although it is prohibited by law in West Papua, rifles are also used for hunting. The hunting sites are related to clan and traditional forests, which include primary forest, secondary forest and mixed or forest gardens. Several hunters require access to a boat to reach into their hunting grounds, which are often located in distant areas. Renting a boat is relatively costly, and it is not cost-effective if there is no harvest at hunting sites.

The meat of rusa deer (venison) and wild pigs has become the target of wildlife trade in the region. There are several wildlife trade spots and local markets for venison and other wild meats in the towns of Sausapor and Fef in Tambrauw regency, and in the provincial cities of Sorong and Manokwari. Hunters with access to local markets in towns were able to pursue commercial hunting and sell the harvest by themselves. The others had to bring their capture to the wildlife trade spots and sold to middlemen. Regarding the wildlife trade, the price of venison and wild pig meat sold in the cities was much more expensive around 60,000 IDR per kg meat (1 USD = 13,800 IDR), and 40,000 IDR in the towns, but the benefits usually go to middlemen and meat handlers. In addition, the antlers and the pelt of rusa deer are valuable and may bring additional income for families.

4.3 | Managing hunting

To be effective, wildlife management not only requires robust assessment of population abundance of the target species (Latham et al., 2017), but also considerations of other contexts such as ethical and political arguments (Dickman et al., 2015), since conservation is more about people than wildlife (Steinmetz et al., 2014). Moreover, managing an introduced mammal is an especially complex problem, since its effects on native fauna and flora are usually not well understood.

In West Papua, wildlife plays an important role as protein source of local people and recently also for income generation, and therefore many local communities are seriously concerned to manage capture rates of target animals. For centuries, the so called *sasi* system is being applied in the Mollucas and various parts of West Papua when wildlife faces dramatic declines and other natural resources are depleted. *Sasi* refers to a traditional system of natural resource management and includes banning the harvests of resources on the land and in the sea (McLeod et al., 2009). *Sasi forest* and *wildlife* may also describe specific traditional rules and regulations governing access to forest areas and to hunt particular wildlife species. We found that local communities in Tambrauw have developed and implemented '*sasi gereja*' and '*sasi adat*' to avoid overexploitation of forest, wildlife and marine resources. Both *sasi* systems have been implemented in a specific rotation way or within certain agreed periods. For instance, the *sasi* area is divided into multiple sites and forest resources can be harvested in a rotation manner if the population abundance is increased, or as practiced in Syunggak village, wildlife hunting is prohibited for a period of 5 years. According to the clan and community leaders, traditionally, the *sasi* system has been developed for sustainable harvest of wildlife, because the abundance of large-sized wildlife was reduced drastically after intensive harvesting in the previous years. The s*asi* has also been employed to improve ecotourism and wildlife tourism to benefit local communities. Both the *sasi* system and wildlife taboos are two forms of traditional knowledge and beliefs which can provide important mechanisms to support sustainable management of natural resources and biodiversity conservation in the region.

4.4 | Proposing an integrated community-based rusa deer management

With regard to the high population of rusa deer in West Papua and the current pattern of wildlife hunting and trade, management strategies should address the role of rusa deer within the socio-economy of the local people, while also considering impacts of this species on the forest ecosystems. As a first step, we here propose an integrated community-based rusa deer management, which can be implemented by combining multiple stakeholders such as local villagers, traditional institutions, hunters and vendors, government and external experts (Figure 3). As such, government program, traditional ecological knowledge and outcomes of scientific assessments should be incorporated to guide management strategies and resource use decisions within a holistic approach. General guidelines on the sustainable use of wildlife (e.g. monitoring of harvest levels, population recovery capacity) could be communicated, but recognition and understanding of the local context is necessary for the application of such guidelines (Prescott-Allen & Prescott-Allen, 1999).

Such community-based management relies on acquisition and adequate communication of information (Bodmer & Puertas, 2000). In this context, for example, the community and traditional institutions could be encouraged and recognized as the main responsible stakeholders for implementing rusa deer management in their traditional forests. Since the *sasi* system and wildlife taboos have been applied in Tambrauw region, these traditional regulations could be used as important principles of management strategies and conservation. However, the local communities essentially require assistance, guidance and cooperation from other stakeholders on the technical aspects, such as how to know the sustainable level of rusa deer offtake. Ecological studies that focus on population assessments may generate useful information on the impact of hunting as well as on the effectiveness of management strategies on animal population abundance. Such scientific information should practically guide local people on sustainable resource use while recognizing the socioeconomic realities of the communities (Bodmer & Puertas, 2000). Hunting registers need to be established in local villages, as an efficient control measure and a key factor for the sustainability assessment. Hunters and vendors should report their hunting and trade activities to the traditional council, so hunting on threatened native fauna can be identified and regulated. The trade scheme should be properly monitored and managed so that hunting merely targets the introduced/invasive species as the trade incentives may otherwise escalate hunting pressure on native species in the region (Pangau-Adam & Noske, 2010).

Another important aspect of an integrated rusa deer management would be the establishment of a special regulation for commercial hunting and trade. There is an existing provincial law on the 'Sustainable Forest Management' in West Papua (Perdasus No. 21/2008), but it does not specifically address wildlife hunting. Traditional councils together with the Tambrauw regency government could plan and set up regulations on potential types of exploitation of wildlife and forests. In this process, they should recognize and incorporate information and advice from professionally trained external experts in wildlife and habitat management, and should also particularly consolidate the attitudes of hunters and traditional institutions in the development of regulations. As the application of snares by hunters can be detrimental to native wildlife species, the impacts of different hunting techniques should be clearly described in the newly enacted regulations, directing

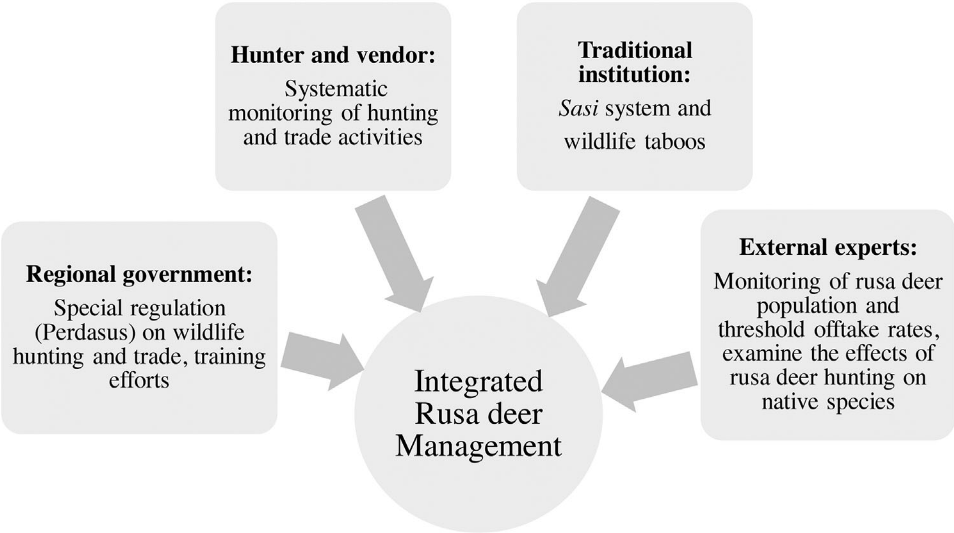

FIGURE 3 A proposed integrated sustainable rusa deer management in the Tambrauw region, West Papua, Indonesia

to prevent the use of shotguns and snares to hunt, and instead promote traditional hunting methods.

Rusa deer management should also improve strategies of wildlife trade in the Tambrauw regency. As the majority of the wildlife trade benefits usually go to middlemen and meat handlers rather than local hunters, it is a big challenge for them to act as key players. The government programs that provide support to empower the small-scale community entrepreneurship (A. Major 2019, personal comm.) can be addressed to train local hunters and their families in both wild meat handling and marketing. Also, in combination with the initiatives of conservation NGOs such as the Blue Abadi and GIZ-FORCLIME, government programs can deliver such infrastructure, for example boat, refrigerator boxes and solar cell power. Such infrastructural development and training are necessary for local hunters and meat vendors, for effective handling and marketing of hunted animals (e.g. rusa deer, wild pig).

Furthermore, other important factors that need to be included in the proposed rusa deer management are the current hunting pressure faced by threatened native fauna and the understanding of a balanced ecosystem. Uncontrolled hunting and illegal wildlife trade have become one of the major causes of the population decline of endemic fauna in Papua such as cassowaries and crowned pigeons (Johnson et al., 2004; Pangau-Adam et al., 2015; Keiluhu et al., 2019). In order to maintain the population of native fauna in the Tambrauw region, hunters could be encouraged to focus their hunting efforts on the introduced species (i.e. rusa deer and wild pig), which both are abundant in the region. Basically, this issue can only be addressed by effective law enforcement measures (Pangau Adam & Noske, 2010). Therefore, the redirection of hunting from native to introduced/invasive species, and from vulnerable to resilient species, could be incorporated in the special regulation on wildlife hunting. In addition, it is well known that unsustainable harvest will lead to population decline of species or, in the worst case, it can even cause extirpation (Davis et al., 2016). However, the extermination of the introduced/invasive herbivores that are well adapted and having a high density is impractical through natural predators or local human hunters (Davis et al., 2016), especially since the natural predators of these mammals are absent. Therefore, continuous monitoring on rusa deer distribution, abundance and harvest rates needs to be conducted to assess population trends and impacts of hunting. The results should be delivered to traditional institutions to improve the management.

Ungulates such as rusa deer are known as ecosystem engineers, since they maintain the heterogeneity of landscapes, but when they are introduced into regions where they become invasive, they can adversely affect local biodiversity (Gordon et al., 2004; Davis et al., 2016). For instance, in New Zealand (Allen et al., 1984), Australia (Keith & Pellow, 2005) and south-western PNG (Bowe et al., 2007) the vegetation structure has been substantially altered by browsing of rusa deer. Also, in the Tambrauw region rusa deer browse saplings of various trees (e.g. palms), and may consequently prevent or reduce regeneration of the forest. However, our analysis does not directly test this hypothesis, rather it suggests that further study is needed to examine the impacts of rusa deer on forest structure and interspecific competition with native herbivores in Papua.

In conclusion, the proposed integrated community-based rusa deer management in the Tambrauw region could lead to successful conservation outcomes if trust is built between stakeholders, and if they are willing to share information and commit to cooperate. A study in rural areas in PNG reported that village-based monitoring programs were feasible when undertaken in collaboration with non-local scientists or trained workers (Johnson et al., 2004). These should be encouraged as a means by which communities and management agencies can evaluate the sustainability of wildlife harvesting rates (Johnson et al., 2004). Likewise, Bodmer and Puertas (2000) illustrated how collaboration between scientists, NGO workers and local hunters has achieved sustainable harvest rates through collective monitoring and evaluation of wildlife offtake. The progress towards sustainability could be achieved only by integrating both human dimensions and ecological factors, and not trading them off against each other (Prescott-Allen & Prescott-Allen, 1999). The community-based effort might function as a potential conservation strategy in the Tambrauw region, if there is adequate evidence-based information on managing wildlife hunting in a form that is compatible with the socioeconomic capacities and aspirations of the local people.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

MPA, MS and MW conceived the ideas and designed methodology. MPA led the field project. MPA, MS and MF collected the data. MPA and MS analysed the data. JT analysed the spatial mapping. MPA and MS led the writing of the manuscript. All authors contributed significantly to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data are available in the Dryad repository, https://doi.org/10.5061/dryad.fttdz08tp (Pangau-Adam et al., 2021).

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SUPPORTING INFORMATION

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