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A sustainable way of agricultural livelihood: edible bird's nests in Indonesia

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ABSTRACT

Edible birds' nests (EBNs) have traditionally been produced in Southeast Asia. Indonesian farmers construct buildings for swiftlets and harvest their nests. EBN farming does not directly degrade forest resources and is therefore considered a sustainable means of production, whereas the expansion of other agricultural activities often relies on the degradation of natural resources. This study examines the relationship between natural resources and agricultural livelihoods, focusing on Indonesian EBN farmers. Using survey data that we collected in 2017, combined with satellite information on the extent of the forest in Central Kalimantan, Indonesia, we measured production efficiency and identified the natural and social factors that enhance production performance. The results show that a forest extent ranging between 2,000 and 6,000 meters from nesting building is positively associated with the production efficiency of EBN farming, perhaps because extensive forest could help swiftlets to collect food and build nests. Conversely, while EBN farming is a sustainable and profitable option, the initial costs of constructing buildings to house swiftlets may deter farmers from participating in the process.

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Introduction

Forest management has been recognized as essential to ecosystem services and biodiversity conservation. Nevertheless, forest degradation has increased due to land-use changes and a lack of understanding of the degradation's economic consequences, particularly in developing countries. Although ecological studies have recognized the substantial contribution of tropical forest conservation to biodiversity (e.g., Gibson et al. 2011; Mitchell et al. 2018), little is known about the economic benefits of tropical forest conservation other than carbon sequestration (Pandeya et al. 2016; Yamamoto et al. 2019). Consequently, the value of tropical forests may be underestimated in conservation policies.

Edible birds' nests (EBNs) are created by some swiftlet species – the white-nest swiftlet (*Aerodramus fuciphagus*) and the black-nest swiftlet (*Aerodramus maximus*) – and harvested by farmers for home consumption, as food and medicine, in Southeast Asia (Chua and Zukefli 2016; Hao et al. 2015). The nests are produced in Indonesia, Malaysia, Vietnam, and China. This natural product has been used as a traditional medicine and, most often, as a luxury ingredient in bird's nest soup, particularly in China, for more than 400 years (Dai et al. 2020; Hobbs 2004). EBNs are one of the most valuable animal by-products (Marcone 2005), and their market value is around USD 1,000–10,000/kg depending on their grade, shape, type, and origin (Hao and Rahman 2016). Male swiftlets usually build EBNs over a period of 35 days during the breeding season (Chua and Zukefli 2016). In the past, the nests were harvested from caves – particularly the enormous limestone caves at Gomantong and Niah in Borneo – and Mardiastuti (2011) surmised that swiftlet farming started in East Java in 1880. Swiftlet farming in Indonesia can be categorized according to three periods: the first period, from the 1900s to the 1950s, when farmers relied on chance and good luck for the production; the second, from the 1950s to the 1990s, when individual farmers and house owners developed management methods that they kept secret from each other; and the third, from the 1990s to the present day, during which period EBN management methods became more intensive and shared between house owners. With the increase in demand for EBNs since the late 1990s, EBNs have been produced in purpose-built nesting building, usually constructed of reinforced concrete. These nesting houses are typically found in urban areas near the sea because the birds tend to flock in such places. The EBN production industry has been expanding, particularly in such places as the province of North Sumatra or the Pak Phanang District in Thailand. The nests are mostly exported from those places to markets in Hong Kong, which is the center of EBN world trade. Annual EBN sales in Hong Kong are currently valued at approximately HKD 2 billion (USD 257 million) (Nation Thailand

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2021), although most of the final consumers are located in mainland China. China is the world's largest consumer of EBNs, accounting for more than 90% of world consumption (Nation Thailand 2021). Over the three periods mentioned previously, Indonesia became the largest bird's nest producer in Southeast Asia, exporting around 2,000 t/year, followed by Malaysia at 600 t/year, and Thailand at 400 t/year (Nation Thailand 2021). Estimates suggest that the EBN industry accounts for 0.5% of the Indonesian gross domestic product (equivalent to about a quarter of the country's fishing industry). In Thailand, the trade value of natural and farmed EBNs combined is estimated at around THB 10 billion (USD 307 million) per year. Globally, the industry value is estimated at around USD 5 billion (Bloomberg 2013), and Hong Kong (China) and the United States are the largest importers of these nests.

This paper examines the economic benefits of tropical forests, exploring the effects of social factors and natural resources on swiftlet EBN production. Swiftlets typically construct their nests in caves located in or near coastal regions or tropical rainforests (Chua and Zukefli 2016), and the preferred foraging habitat of cave-nesting swiftlets is above (or in some cases, below) the canopy of extant rainforests (Stimpson 2013). The number of swiftlets has been decreasing, coinciding with large-scale logging operations and the establishment of oil palm plantations (Stimpson 2013). This decrease is probably due to deforestation reducing the number of aerial arthropods on which swiftlets feed. While there is ecological evidence that natural resources provide habitats for these insects (e.g., Gibson et al. 2011; Koh et al. 2011; Mitchell et al. 2018), there is no evidence quantifying the effects of natural resources on EBN production. Consequently, we hypothesized that natural resources enhance EBN productivity. Using survey data combined with satellite information on the forest extent in Central Kalimantan, Indonesia, we measured how the forest ecosystem contributed to EBN production performance.

For three reasons, this paper elucidates how social factors and natural resources contribute to EBN farmers' production efficiency and incomes and provides essential information for policymakers planning sustainable forest management in the rural areas of developing countries. First, quantifying the effect of natural resources (such as forests) on agricultural production can help to enhance forest conservation. Generally, forest conservation policies fail to consider the benefits of ecosystems; hence, examining the potential benefits of forest extent on agricultural production can contribute to forest conservation policy in the context of sustainable development in rural areas. Second, improving farmers' incomes is vital for alleviating poverty in developing countries. Most of the impoverished population settles in rural areas and engages in agricultural activities; for example, in Indonesia, the agricultural sector plays a significant role in economy, employing 70% of the labor force in rural areas (McCulloch, Timmer, and Weisbrod 2011). Third, this study based its empirical results on original EBN production data collected by our field survey. While the importance of EBN exports is increasing, its socioeconomic effects on farmers have not been examined. This study aims to fill this gap.

Materials and methods

We adopted a two-stage approach to investigate the effects of social and natural resource factors on the efficiency of EBN production. Initially, using data envelopment analysis (DEA), we determined the relative efficiency scores for EBN production in Central Kalimantan, Indonesia. The efficiency scores were then regressed using social and natural resource factors to investigate associations between them. We used QGIS 2.14.12, DEAP Version 2.1, and Stata 14.2 to conduct the geographical, data envelopment, and statistical analyses.

Data collection

The data on EBNs and social factors for the analyses were obtained through a field survey conducted in January 2017 in five villages in the Pulang Pisau district, Central Kalimantan, Indonesia (Figure 1). We hired and trained five investigators from the University of Palangkaraya to conduct the field survey, since they were able to communicate with farmers using the Indonesian and Dayak languages. The Pulang Pisau district is bordered by the Katingan district in the west, Kapuas district in the east, Gunung Mas district in the north, and the Java Sea in the south. The district's tropical climate is characterized by relatively high humidity (75–87.4%) and a temperature ranging from 20°C to 35.8°C. Almost 30% of the total land area is covered by peat swamp forests. The ecosystem's carbon storage potential and rich biodiversity make it the most important land cover type for conservation in the district. The typical land use in the district is for oil palm plantations and farmland, each covering almost 10% of the district area.

The Government of Indonesia implemented the Mega Rice Project between 1996 and 2000 to increase national rice production and encourage the migration of people from other islands to Kalimantan; however, the project failed. Since the project was abandoned, EBNs have been harvested as an alternative source of income in the Pulang Pisau district (Jagau, Noor, and Verhagen 2008). This situation allowed us to investigate the sustainability of EBN production and its relationship with farmers' livelihoods. We visited five villages and identified building owners who were willing to participate in the investigation in January 2017. Of these, we randomly chose 50 EBN farmers with whom to conduct

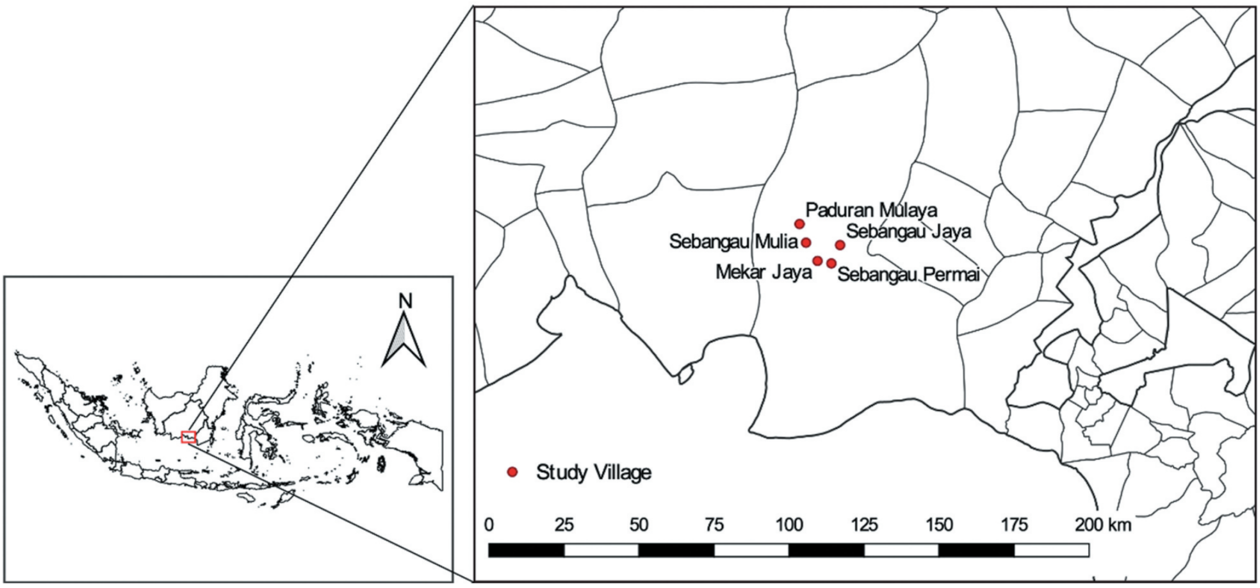

Figure 1. Study sites: Pulang Pisau district, Central Kalimantan province. Pulang Pisau district is located at latitude 3.11 ° south and longitude 113.86 ° east. The red dots indicate our study villages.

Table 1. Descriptive statistics for the sample.

Variables	Mean	S.D.	Min.	Max.
Value of production (Indonesian Rupiah [IDR]/kg) (IDR 10,000 ≈ USD 0.07)	7,794	660.7	6,000	9,800
Annual harvest (kg)	13.94	13.26	0.20	60.0
Construction cost (IDR 1,000s)	104,400	669,49.87	20,000	400,000
Dimension (m^3)	458.604	255.768	36	1,500
Debt	0.660	0.479	0	1
Forest extent within range of 2,000–6,000 m	0.162	0.010	0.141	0.175
Forest extent rate within range of 6,000–10,000 m	0.228	0.026	0.172	0.247
Pond	0.400	0.495	0	1
Concrete material	0.480	0.505	0	1
One window	0.073	0.260	0	1
Number of windows	1.68	0.551	1	3
Construction year	4.680	2.684	1	14
Annual maintenance cost (IDR 1,000s)	1,971	1,957	0	10,000
Pesticide	0.520	0.505	0	1
Spray smell	0.940	0.240	0	1
Tape recorder	0.780	0.418	0	1
Rubber cultivation	0.200	0.404	0	1
Rice cultivation	0.220	0.418	0	1
Male owner	0.860	0.351	0	1
Observations		50		

face-to-face interviews. During the interviews, we asked the owners for information on the quantity of EBNs they had harvested in the previous year, the type of nesting buildings they used, their harvesting techniques, and their demographic characteristics. To the best of our knowledge, there is no official information regarding the number of buildings for swiftlets in Pulang Pisau district; hence, the sample of 50 farmers may have been relatively small, unrepresentative, and therefore potentially biased. Nevertheless, the analysis we conducted constitutes the first insight into the livelihoods of EBN farmers.

Table 1 summarizes the descriptive statistics for our sample. The total number of observations is 50 nesting building . The main variable of interest in this study are the annual harvest from each building. The variables used to assess production efficiency include natural resource factors, such as forest areas and ponds, and social factors, such as construction materials, number of windows in nesting buildings, maintenance costs, and the pesticides used by farmers.

We determine natural resources based on the findings of an ecological study (Burhanuddin and Noor 2017). Burhanuddin and Noor (2017) observed that swiftlets exhibit predatory activity across a range of 2,000 to 6,000 meters from their birdhouses. In this study, forest extent was defined as the forest extent within a 2,000-–6,000-meter radius of a nesting building. Additionally, we used a forest cover range within a 6,000–10,000-meter circumference of a building for the robustness tests. If our hypothesis is correct, forest cover between 6,000 and 10,000 meters would not affect EBN production performance because that range would exceed the swiftlets' active feeding area

(Burhanuddin and Noor 2017). The existence of ponds was based on farmers' self-reported information. Farmers were asked, "Do you have any ponds around the swiftlet buildings?" Forest data was obtained from satellite observations provided by Hansen et al. (2013); the portion of forest cover area was calculated within a range of 2,000 to 6,000 meters from each building. Figure A1 in the Appendix shows the forest cover map for the study site. This dataset is publicly available at https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html. The data on the global forest extent was obtained from multispectral satellite images at a spatial resolution of 30 meters. *Pond* was a dummy variable that took the value of one when there was a pond in the EBN production area and zero otherwise. We assumed that ponds would play a similar role to forests because both natural resources provide habitats for various living organisms, including insects, that are food for swiftlets and provide the materials used for EBNs. A total of 40% of farmers had a pond near their buildings, and 24 (48%) of the 50 buildings were constructed with concrete. In Kalimantan, the buildings could be made of either concrete or wood (Figure 2). The concrete buildings tended to be taller than the wooden buildings; however, concrete buildings were more expensive to build than wooden buildings, and it might be valuable to examine whether construction materials affect rural productivity. The annual harvest was the sum of the monthly harvests from December 2015 to November 2016.

Concrete material was a dummy variable that took the value of one when the building was made of concrete and zero otherwise. The *construction year* variable represented the average age of a building, and the data showed an average of 4.68 years for building age. We also collected information on the characteristics of the owners; for instance, we verified whether the building owners also engaged in other agricultural work. Engaging in other agricultural work implied that the owner had other sources of income, that might affect farmers' EBN production efforts. A total of 20–22% of building owners also worked in rice and rubber cultivation. We also investigated whether the gender of owners and alternative agricultural activities affected EBN production performance.

Measuring EBN production performance

We employed output-oriented DEA to assess EBN production efficiency. DEA has been used as a tool for measuring and evaluating performance in various scientific fields (Cooper, Seiford, and Zhu 2011). The main advantage of DEA is that it does not require any prior assumptions about the underlying functional relationships between inputs and outputs (Seiford and Thrall 1990). Output-oriented DEA measures the production efficiency of a decision-making unit (DMU) as the relative distance from the possible production frontier to the output expansion. Each DMU has several inputs and outputs. Inputs represent the resource consumption and monetary investment levels of each DMU, whereas outputs represent the effects of inputs on each DMU. The relative efficiency of the DMUs could also be calculated. A DMU ranged from 0 to 1, and DMUs are more highly efficient when the evaluated object is relatively efficient. The efficiency of the k-th DMU (k = 1, 2, . . ., K) was defined as the maximum value of D_k in the following linear equation:

$$\begin{aligned} &\max D_k \\ &s.t. \sum_{k=1}^{K} \lambda_k y_{ik} \geq D_k y_{ik} \\ &\sum_{k=1}^{K} \lambda_k x_{jk} \leq x_{jk} \\ &\lambda_k \geq 0 \\ &\sum_{k=1}^{K} \lambda_k = 1, \end{aligned} \tag{1}$$

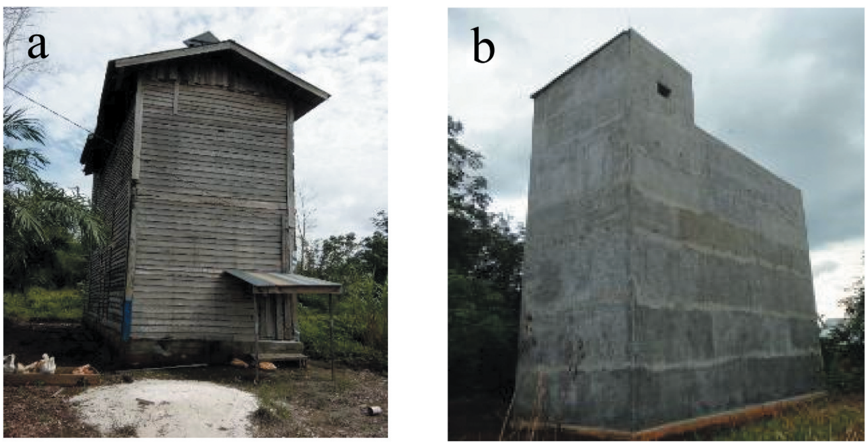

Figure 2. Photographs of EBN buildings constructed of (a) wood and (b) concrete.

where x_{jk} denotes the j-th input and y_{ik} denotes the i-th output of the k-th DMU. D_k denotes the efficiency score of the k-th DMU, λ_k the weight for the k-th DMU, y_{ik} the i-th output for the k-th DMU, and x_{jk} the j-th input for the k-th DMU. When evaluating the k-th DMU, the relative efficiency was set as the objective function with constraints on other DMUs efficiencies. The last line in Equation 1 indicates the assumption of a variable return to scale (VRS) of production. This model employed a ratio for VRS efficiency to obtain the efficiency scale. Each DMU was a building. Building owners made various decisions regarding the inputs to EBN production. In our analysis, we estimated the relative efficiency score by considering two necessary inputs for EBN production in each building – construction cost and the dimensions of the building – whereas the output was the yearly production of EBNs.

The efficiency score was measured using the necessary input factors for EBN production. We then estimated how the efficiency score could be affected by unnecessary inputs such as natural factors, building characteristics, and the farmers' production efforts.

Natural resources and social factors

In this subsection, we explain how the DEA approach was used to calculate the social and natural resource factors associated with the efficiency scores. Ordinary least square (OLS) estimates are thought to be biased and inconsistent when the dependent variable is censored. In other words, our efficiency scores were censored at 1 and thus required a Tobit regression for the estimation:

$$\tilde{E}S_i \beta' X_i + \in_i$$
$$ES_i = \begin{cases} 1 \; if \; \tilde{E}S_i \geq 1 \\ \tilde{E}S_i \; if \; \tilde{E}S_i \geq 1, \end{cases} \quad (2)$$

where ES_i is the latent dependent variable for building i; X_i is the vector of the independent variables, including the social and natural resource factors; and $\widetilde{ES_i}$ is the observed efficiency score obtained from the DEA. The model could be estimated using the maximum likelihood method. Although we employed a Tobit model, it was worth estimating the effects using OLS estimation. The results of the OLS estimation are presented in Table A1 and were similar to the results for the Tobit model.

Results

Descriptive analysis of the farming revenue from EBNs

Table 1 reports the data for the production and sale price of EBNs reported by the farmers. The average annual revenue from EBN farming, roughly calculated by multiplying the annual production of 14 kg by the sale price of 7,794,000 IDR/kg (USD 538), was IDR 109 million (USD 7,638). This revenue was more than twice the average agricultural revenue (e.g., of rice and rubber farmers) in Central Kalimantan – USD 3,476.5 (Yamamoto and Takeuchi 2012); thus, EBN farming is profitable and attractive to farmers in rural areas.

However, two problems relating to entry costs and stable production remained. The initial cost for constructing a building was IDR 104 million (USD 7,154.5), which is financially infeasible for many ordinary farmers in Indonesia. In our sample, 33 of the 50 building owners (66%) borrowed money to construct their buildings. The high initial cost of EBN farming is a barrier for farmers wishing to start EBN harvesting and affects the growth of the EBN farming industry. Also, farmers generally have several partners who invest jointly in the construction of the buildings. In these cases, farmers do not receive all the profit: they share it.

Additionally, 10 of the 50 building owners (20%) reported that their total production was less than 3 kg for the period from December 2015 to November 2016. This low production implies that farmers may receive minimal or zero income for several months, and for farmers who rely on their income from agriculture, lower production degrades their living standards; therefore, the unstable production outcomes could discourage farmers from participating in EBN farming. Productivity and stability issues should be addressed to make EBN farming a more viable and sustainable method of achieving a livelihood.

DEA efficiency scores for EBN production

We measured the EBN production efficiency in terms of the actual building production relative to the estimated building production. Figure 3 shows the results for the output-oriented DEA scores. The estimated mean and standard deviation of the DEA scores were 0.381 and 0.316, respectively. The results indicated that many buildings had low EBN production efficiency, while 5 out of 50 DMUs were 100% efficient. Efficiency scores lower than 0.5 accounted for 72% of our sample.

Effects of natural resources and social factors on EBN production

The results of the Tobit regression are shown in Table 2. Column 1 shows the relationship between efficiency and forest extent without controlling for inputs and farmers' characteristics. We then included the building characteristics in Column 2, the farmers' characteristics in Column 3, and the farmers' other agricultural production in Column 4.

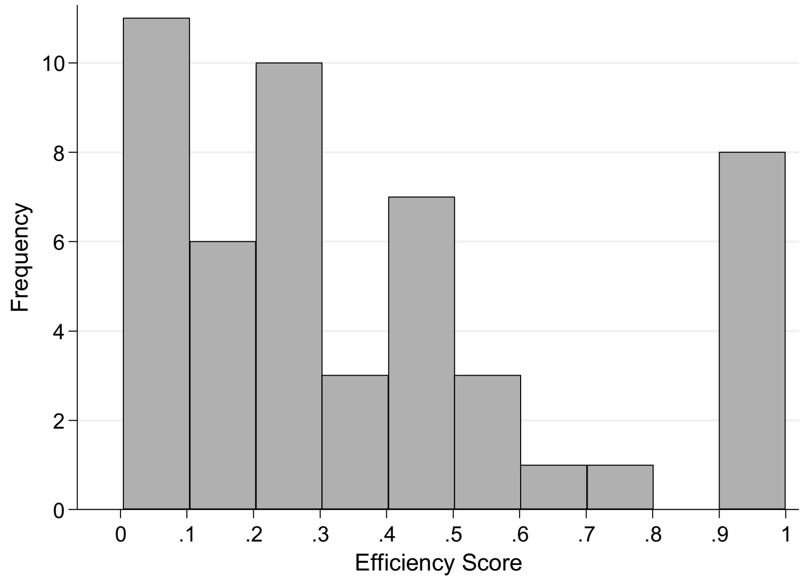

Figure 3. Histogram of efficiency scores. The variance of the efficiency scores was large. Eleven samples out of 50 had an efficiency score below 0.1, whereas 8 samples had an efficiency score higher than 0.9.

The estimation results showed that forest extent had significantly positive coefficients for the efficiency scores of EBN production. The coefficients of forest cover were robust according to every specification, implying that our results were not biased by increasing the number of explanatory variables.

Table 2. Results of the Tobit regression.

	1	2	3	4
Forest extent within A range of 2,000–6,000 m	0.073**	0.085***	0.089***	0.086***
	(0.035)	(0.029)	(0.028)	(0.030)
Pond	0.150	0.159	0.204	0.222
	(0.130)	(0.121)	(0.133)	(0.160)
Concrete material		0.252*	0.278*	0.284*
		(0.127)	(0.141)	(0.151)
Number of windows		0.067	0.049	0.043
		(0.112)	(0.120)	(0.128)
Construction year		−0.019	−0.017	−0.017
		(0.059)	(0.056)	(0.059)
Construction year squared		0.003	0.003	0.003
		(0.005)	(0.005)	(0.005)
ln(maintenance costs)		0.001	0.002	0.004
		(0.009)	(0.010)	(0.012)
Pesticide			−0.389	−0.397
			(0.232)	(0.238)
Pheromone spray			−0.373**	−0.383**
			(0.158)	(0.155)
Tape recorder			−0.325	−0.336
			(0.223)	(0.218)
Rice farmer				−0.003
				(0.160)
Rubber farmer				0.001
				(0.110)
Male owner				−0.077
				(0.157)
Constant	−11.950**	−14.214***	−14.031***	−13.536**
	(5.791)	(4.899)	(4.617)	(5.043)
Observation	50	50	50	50
Pseudo R-squared	0.251	0.443	0.479	0.486
Log-likelihood	−16.864	−12.532	−11.730	−11.577

a) the dependent variable is the efficiency score; b) the estimations were performed using a Tobit estimator; c) every estimation included the village ID to control for variations in efficiency between villages; d) each model included natural factors for Column 1, building characteristics for Column 2, farmers management efforts for Column 3, and alternative income sources of farmers for Column 4; e) robust standard errors are shown in parentheses; and f) * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Among the social factors, concrete building materials positively affected the efficiency scores, implying that buildings constructed with concrete increased the efficiency scores. Conversely, the number of windows did not significantly affect the efficiency scores in Columns 2–4. We included the characteristics of farmers, such as their main production outputs (rice and rubber) and gender, in the estimation in Column 4. The results indicated that the characteristics of farmers and the efficiency scores were not significantly associated.

Using the alternative range of forest extent

For robustness tests, we obtained estimation results using an alternative range of forest extent. We estimated models with the explanatory variable of forest extent set at a range of 6,000 to 10,000 meters from each building. Table 3 reports the results. All models showed that the coefficients for the forest extent were small and statistically non-significant for the efficiency scores, indicating that EBN productivity was not associated with forest cover farther out than 6,000 meters but specific to the range between 2,000 and 6,000 meters.

Discussion

Our results indicated that a forest extent of 2,000–6,000 meters from buildings improved EBN production efficiency. This increase of efficiency due to forest extent may be attributed to the fact that forests provide nest material and food for swiftlets (Petkliang et al. 2017; Quang, Quang, and Voisin

Table 3. Results of robustness tests using a Tobit regression for forest extent ranging between 2,000 and 10,000 meters.

	1	2	3	4
Forest extent within	−0.027	−0.043	−0.056	−0.061
A range of 6,000–10,000 m	(0.117)	(0.120)	(0.123)	(0.116)
Pond	0.212	0.222*	0.240*	0.261
	(0.126)	(0.121)	(0.136)	(0.167)
Concrete material		0.213*	0.218	0.230
		(0.126)	(0.143)	(0.150)
Number of windows		0.051	0.038	0.015
		(0.113)	(0.123)	(0.130)
Construction year		0.003	0.003	0.003
		(0.005)	(0.005)	(0.005)
Construction year squared		−0.000	0.001	0.006
		(0.009)	(0.009)	(0.012)
ln(maintenance costs)			−0.285	−0.271
			(0.239)	(0.238)
Pesticide			−0.314*	−0.307*
			(0.179)	(0.155)
Pheromone spray			−0.199	−0.204
			(0.231)	(0.225)
Tape recorder				−0.044
				(0.161)
Rice farmer				−0.053
				(0.107)
Rubber farmer				−0.153
				(0.155)
Male owner	0.956	1.166	2.043	2.216
	(2.872)	(2.932)	(3.141)	(2.944)
Observation	50	50	50	50
Pseud R-squared	0.160	0.307	0.334	0.358
Log-likelihood	−18.898	−15.602	−14.997	−14.439

a) the dependent variable is the efficiency score; b) the estimations were performed using a Tobit estimator; c) every estimation included the village ID to control for variations of efficiency between villages: d) each model included natural factors for Column 1, building characteristics for Column 2, farmers management efforts for Column 3, and alternative income sources of farmers for Column 4; and e) robust standard errors are shown in parentheses.

2002; Tylianakis, Klein, and Tscharntke 2005). The swiftlets nesting in areas near forests can catch larger amounts of food, such as Homoptera, than those in urban and rural areas (Lourie and Tompkins 2000). This finding was consistent with considerable ecological evidence that the forest plays a vital role as a natural habitat for living organisms; for example, data on butterfly diversity estimated the biodiversity in a primary forest to be five times higher than that in other landscapes, such as plantations (Koh and Wilcove 2008; Koh et al. 2011). Additionally, *A. fuciphagus* prefers forests and wetlands to drylands (Fullard, Barclay, and Thomas 2010; Phach and Voisin 1998). Furthermore, rainforest is an important feeding ground for swiftlets (Stimpson 2013), so a decrease in forest cover reduces the food supply, decreasing the number of swiftlets and thus EBN production efficiency.

This study shed light on the effects of forest extent on EBN production performance. Our findings add to the literature on the contributions of forests to agricultural production. While recent ecological studies have found that forest ecosystem services positively affect agricultural production in several ways, such as via pollination and pest control (e.g., Carvalheiro et al., 2010; Karp et al. 2013; Klein, Steffan-Dewenter, and Tscharntke 2003; Klein et al. 2007; Ricketts et al. 2004; Shackelford et al. 2013), no study has examined the relationship between forest extent and EBN production.

Our results suggest that forests can contribute to farmers' livelihoods. Studies have estimated the incomes from rice production and oil palm plantations in Indonesia (Butler, Koh, and Ghazoul 2009; Yamamoto and Takeuchi 2012), but we have shown that EBN production is an important income source for farmers and more attractive than rice production. This evidence of a relationship between forest extent and EBN production could support sustainable agricultural production through forest conservation in Indonesia.

Regarding the construction materials used, concrete use was positively associated with efficiency. This increase might be attributed to (*A. fuciphagus)* swiftlets' traditional nest building behavior in caves. They prefer caves with high humidity and a low temperature (Phach and Voisin 1998). Using concrete for construction might help to maintain humidity and lower temperatures, unlike the outside environment. Also, concrete buildings can save on construction costs, improving efficiency by reducing the initial expense of construction.

The gender of owners and alternative agricultural income sources were both insignificant. If the farmers engaged in other agriculture work, labor inputs for EBN production could potentially decrease, but EBN production performance was not associated with engaging in other agricultural activities or the gender of owners. This implied that the labor intensity of EBN production is low, enabling farmers to engage in EBN production as an alternative income source, regardless of gender and farming conditions.

Our results showed that forest ecosystem services could benefit farmers by increasing EBN productivity, thus potentially improving farmers' forest conservation behavior. Similarly, quantifying the benefits of ecosystem services is a vital first step for introducing incentives for ecosystem maintenance and supporting conservation; for example, a previous study found that the perceived monetary value of forest ecosystems could increase farmers' forest protection behavior in Indonesia (Yamamoto, Takeuchi, and Köhlin 2020). In our case, forest protection may provide economic benefits for farmers, thus encouraging farmers to improve forest protection.

Our findings have important implications for the expansion of sustainability policies in developing countries. Improving EBN production efficiency can increase farmers' incomes and improve natural resource management in rural areas. In many developing countries, natural resource conservation and rural development are mutually exclusive, as in the context of forest conservation and agricultural extension. However, our findings show that EBN production makes natural resource conservation and regional development possible. Because our results show that forest cover positively impacts EBN productivity, encouraging efficient EBN production management could promote forest conservation efforts among residents by showing that it would be beneficial for them; hence, it may be necessary to introduce mechanisms to secure stable incomes or opportunities, such as providing training, to increase productivity.

Several limitations to this study should be mentioned. First, while we carefully selected the building owners to avoid potential selection bias, the sample size was relatively small. To the best of our knowledge, no official information exists on the number of swiftlet buildings in Indonesia. However, to ensure a representative sample, a comprehensive survey must be conducted on a large scale and target the entire country. Second, the natural resource variables used in the Tobit estimation may correlate with the efficiency scores calculated in the first stage of DEA estimation. In other words, several unobserved variables to control for EBN production (e.g., regional economic circumstances) were excluded from our estimates due to data limitations. Building costs and forest extent might have been considered simultaneously with the condition of the regional economy, but unfortunately, information on the economy at the village level was not available. Third, we cannot clearly identify the mechanism underpinning the relationship between EBN production and natural resources. Although considerable ecological evidence has been provided regarding forests and natural habitats, we could not examine the detailed effect of natural resources on Indonesian swiftlets. Future studies should attempt to address these issues.

Conclusions

This study investigated how natural resources and social factors influence the efficiency of EBN production. We found that a forest extent ranging between 2,000 and 6,000 meters of nest buildings was positively associated with EBN production efficiency. Forest cover could help swiftlets to collect food and nest-building material. The results are in line with ecological evidence showing that natural resources provide habitats for the insects that swiftlets feed on (e.g., Gibson et al. 2011; Koh et al. 2011; Mitchell et al. 2018).

These findings have important implications for forest management in Indonesia. In particular, the results suggest that forest conservation policies should consider the contribution of forests to agricultural production and farmers' livelihoods.

Our study also showed that, on average, EBN farming revenue was IDR 109 million (USD 7,638) per year. Although co-investors or co-owners might have to share that amount, the income from EBN production could still be attractive for rural farmers. However, the initial construction costs and production stability must be considered when planning sustainable development.

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Disclosure statement

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Appendix

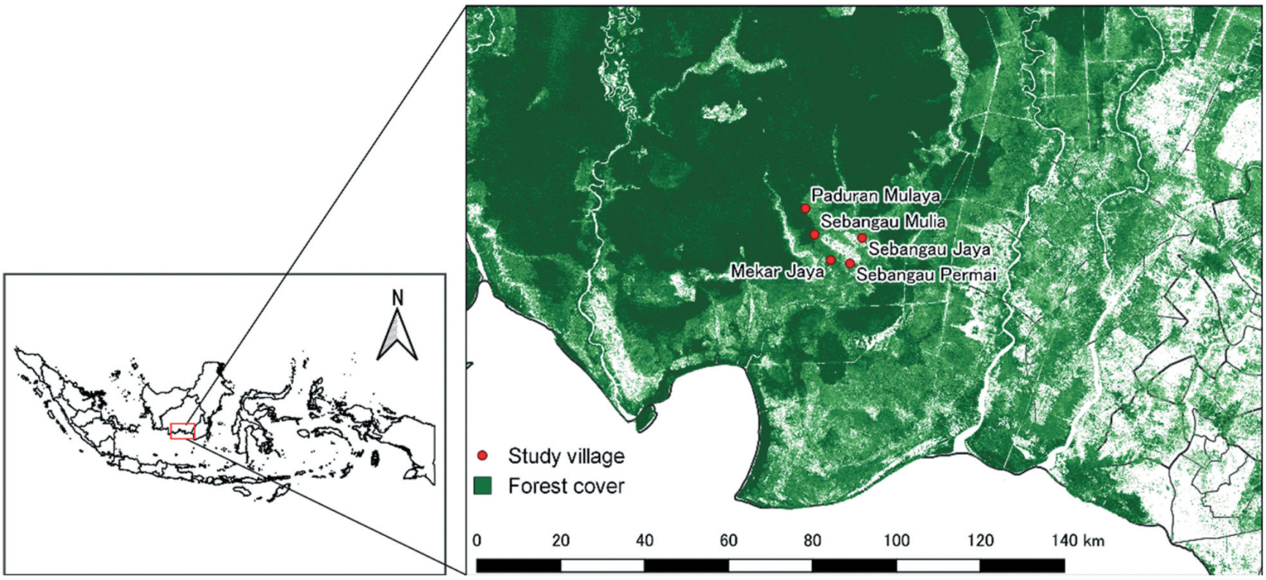

Figure A1. Forest cover map observed by remote sensing in Pulang Pisau district. Red dots indicate our study villages. Green indicates the forest cover. *Source:* .Hansen et al. (2013)

Table A1. Results of OLS estimation.

	1	2	3	4
Forest extent rate within	0.057**	0.068***	0.070***	0.068**
A range of 2,000–6,000 m	(0.023)	(0.021)	(0.021)	(0.025)
Pond	0.155	0.157	0.185	0.193
	(0.128)	(0.134)	(0.154)	(0.195)
Concrete material		0.225*	0.245	0.248
		(0.131)	(0.153)	(0.169)
Number of windows		0.058	0.045	0.042
		(0.115)	(0.128)	(0.143)
Construction year		−0.003	−0.003	−0.002
		(0.055)	(0.055)	(0.060)
Construction year squared		0.002	0.002	0.002
		(0.004)	(0.005)	(0.005)
In(maintenance costs)		0.001	0.002	0.004
		(0.010)	(0.010)	(0.014)
Pesticide			−0.331	−0.340
			(0.249)	(0.267)
Pheromone spray			−0.346*	−0.359*
			(0.190)	(0.197)
Tape recorder			−0.272	−0.284
			(0.249)	(0.256)
Rice farmer				−0.013
				(0.185)
Rubber farmer				0.009
				(0.130)
Male owner				−0.068
				(0.181)
Constant	−9.166**	−11.274***	−11.006***	−10.662**
	(3.813)	(3.572)	(3.471)	(4.204)
Observation	50	50	50	50
R-squared	0.196	0.318	0.339	0.343
Log-likelihood	−7.415	−3.299	−2.504	−2.355

a. The dependent variable is the efficiency score. b. The estimations were performed using an OLS estimator. c. Every estimation included the village ID to control for variations of efficiency between villages. d. Each model included natural factors for Column 1, building characteristics for Column 2, farmers management efforts for Column 3, and alternative income sources of farmers for Column 4. e. Robust standard errors in parentheses. f. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$