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ABSENCE OF DIFFERENTIAL PREDATION ON RATS BY MALAYSIAN BARN OWLS IN OIL PALM PLANTATIONS

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ABSTRACT.—Barn Owls (*Tyto alba javanica*) have been widely introduced in Malaysian oil palm plantations to control rodent pests. However, their effectiveness in regulating rodent populations is unknown. We investigated whether Barn Owls selected prey with respect to size and sex classes based on data from 128 pellets of Barn Owls compared to 1292 live-trapped rats in an oil palm plantation in Malaysia. The birds mostly fed on *Rattus rattus diardii*, the most commonly trapped species. Body mass of prey consumed was predicted based on models derived from measurements from trapped rats. Sex of prey was determined by pelvic measurements with reference to those taken from specimens of known gender. There was no clear selection of prey by Barn Owls in relation to size or sex of prey, and no difference in the body mass of prey between the owls' breeding and nonbreeding seasons. The absence of differential predation in Barn Owls may partly explain the lack of clear evidence that they regulate rodent populations and thus act as successful biological control agents.

KEY WORDS: *Barn Owl*; *Tyto alba*; *Rattus rattus diardii*; *Malaysia*; *prey selection*; *prey size*.

AUSENCIA DE DEPREDACIÓN DIFERENCIAL DE RATAS POR *TYTO ALBA JAVANICA* EN PLANTACIONES DE PALMA DE ACEITE

RESUMEN.—*Tyto alba javanica* ha sido ampliamente introducida en las plantaciones de palma de aceite de Malasia para controlar pestes de roedores. Sin embargo, se desconoce su eficiencia para regular las poblaciones de roedores. Investigamos si *T. a. javanica* seleccionó las presas con respecto al tamaño y clases de sexo, basándonos en datos de 128 egagrópilas de *T. a. javanica* que fueron comparados con datos de 1292 trampas vivas de ratas ubicadas en plantaciones de palma de aceite en Malasia. Las aves se alimentaron principalmente de *Rattus rattus diardii*, la especie más comúnmente atrapada. La masa corporal de las presas consumidas fue predicha con base en modelos derivados de mediciones tomadas de ratas atrapadas. El sexo de la presa fue determinado por mediciones pélvicas con referencia a aquellas tomadas de especímenes de género conocido. No hubo una selección clara de presas por parte de *T. a. javanica* con relación al tamaño o al sexo de la presa, y no hubieron diferencias en la masa corporal de la presa entre las estaciones reproductivas y no reproductivas de *T. a. javanica*. La ausencia de depredación diferencial en *T. a. javanica* puede explicar en parte la falta de evidencia clara de que esta especie regula las poblaciones de roedores y, por lo tanto, de que actúa como agente exitoso de control biológico.

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In many parts of the world, Barn Owls (*Tyto alba*) feed primarily on small mammals, particularly rodents (Taylor 1994). In some regions, the placement of nest boxes has resulted in Barn Owl occupancy in agricultural areas, including oil palm plantations, with the goal of providing biological control of rodents (Duckett 1991, Hafidzi and Na'im 2003b, Ojwang and Oguge 2003). Although Malaysian Barn Owls (*T. a. javanica*) were formerly considered vagrants in peninsular Malaysia, they became established following the increase in rats with the advent of oil palm plantations (Lenton 1984) and are now distributed throughout the country (Malaysian Nature Society 2005). Whether Barn Owls are effective in regulating rodent pest populations in the plantations is uncertain (Wood and Chung 2003). Computer modeling (Smal et al. 1990) suggested that Barn Owls could regulate rodent populations when rat numbers were relatively low, but predicted that, without external aids such as rodenticides, owls would be unable to reduce rodent populations when rats were numerous.

Being important pests of oil palms, rodents cause large losses in crop production. These losses were valued at over a hundred million Malaysian Ringgit (RM) or US\$ 32 million annually for the industry in Malaysia in the 1980s (Basri and Halim 1985). At present many oil palm plantations rely heavily on chemicals such as anticoagulant poisons for control of rodents. In addition to the costs involved, chemical control also causes physiological resistance in target animals (Smith et al. 1993, 1994, Baker et al. 2007) and secondary poisoning of nontarget animals (Stone et al. 1999, Baker et al. 2007). Thus, the use of Barn Owls as an alternative method of control is of interest to plantation managers.

In the wild, predators that demonstrate a predatory preference may affect prey numbers and community structure (Dickman et al. 1991) and thus influence population dynamics. A predator that selectively feeds on sex or age classes may skew population sex ratios, reduce reproduction, or alter the social structure of prey populations (Longland and Jenkins 1987, Andreassen and Gundersen 2006). Selection of certain prey groups is often associated directly with the morphology and behavior of the prey (Derting and Cranford 1989) and indirectly with habitats (Trejo and Guthmann 2003). For example, strongly territorial individuals may travel shorter distances (Vassallo et al. 1994, Bellocq 1998), whereas juvenile small mammals tend to dis-

perse further (Sinclair et al. 1990), thus making them more vulnerable to predators.

Differential predation has been described in numerous owl species, e.g., Short-eared Owls (*Asio flammeus*; Blem et al. 1993), Eurasian Eagle-Owl (*Bubo bubo*; Donazar and Ceballos 1989), Great Horned Owls (*Bubo virginianus*; Longland and Jenkins 1987, Rohner and Krebs 1996), and Eastern Screech-Owls (*Otus asio*; Marti and Hogue 1979). Several studies of Barn Owls have described their tendency to feed on either smaller (Dickman et al. 1991, Leonardi and Dell'Arte 2006, Granjon and Traoré 2007) or larger prey (Derting and Cranford 1989, Castro and Jaksic 1995), depending on seasonal changes in prey populations or habitat conditions. Although differential predation by Barn Owls has been demonstrated, they may not be truly selective predators and may readily switch to other prey species (Morton and Martin 1979, Heywood and Pavey 2002, Tores et al. 2005) or sizes (Muñoz and Murúa 1990, Smal 1990, Gubanyi et al. 1992), depending on prey abundance.

The study of differential predation by size and sex classes of prey is important for understanding the potential success of a biological control agent, such as the Barn Owl, in oil palm plantations where rodents are abundant. Hence, the goals of our study were to assess (1) whether there was differential predation by Barn Owls on size- or sex-classes or species of their main prey, and (2) whether there were changes in the selection of prey between the owls' breeding and nonbreeding seasons.

METHODS

This study was conducted in the Labu Estate (2°45'N, 101°49'E) in Negeri Sembilan state in southwestern peninsular Malaysia. The plantation covered an area of 2569 ha and had sandy clay soil and undulating terrain; it had several small streams and an annual rainfall of about 2725 mm that falls primarily on about 127 d, with most precipitation in March and April (data from Malaysian Meteorological Department). Biological control of rodent pests using Barn Owls was being practiced in the plantation concurrently with chemical control using warfarin. Nest boxes for owls, which likely were installed several decades ago, were present at a density of one nest box per 10 ha throughout the plantation. Barn Owls in the study area bred between November and February, although Lenton (1984) indicated that they nest in different months of the year at some specific sites in peninsular Malaysia.

We trapped rodents and collected regurgitated Barn Owl pellets during seven periods from November 2007 to December 2008, and examined rodent bones obtained from specimens trapped during November and December 2008. Six study plots of 5 ha were established, scattered throughout the plantation, with a mean minimum distance of 960 ± 177 (SD) m between plots; each plot had a nest box occupied by Barn Owls located approximately in the middle of the trapping grid. In each plot, we trapped rodents using 200 cage traps ($280 \times 140 \times 100$ mm; 10–20-mm mesh) placed in a 10×10 grid, with two traps placed at each station, and 30-m spacing between stations. Traps were baited with salted fish, checked in the morning and rebaited daily for three consecutive nights.

We identified all captured rats, sexed them by examination of reproductive organs, and weighed them using a spring scale. Each animal was marked with a unique pattern of ear-notches and punched holes, and released. For reference specimens, we sexed and weighed 112 animals trapped between November–December 2008, then euthanized them using chloroform. These specimens were numbered using plastic tags, wrapped in mesh-like cloth, and buried for four weeks to allow decomposition. We then retrieved the major bones (skull, humerus, femur, pelvis, scapula, and tibio-fibula) from each specimen and measured them to the nearest 0.01 mm using calipers.

Between November 2007 and December 2008, we collected pellets from all six nest boxes directly from the nest boxes or from the ground under the nest boxes. Pellets were dried at 60°C for at least 48 h and then soaked in 0.5M NaOH. All major bones from every pellet were picked out, washed, dried, and measured before being stored in plastic bags labelled with the date and plot number. We examined the anterior palatine foramen (Harrison 1962) and lower molar (Lekagul and McNeely 1977) to identify species, particularly to differentiate between *Rattus rattus diardii* and *R. argentivoenter*. *R. tiomanicus* was identified by the presence of an anterolabial styloid on the second lower molar (Lekagul and McNeely 1977).

To facilitate the assessment of size and sex classes of rodents eaten by owls, we measured four dimensions of jaws (dentary length, dentary height, maximum dentary height and diastema length; Moyer et al. 1984, Dickman et al. 1991) and three of pelvises (pubis length, pubis width, and ischium length; Brown and Twigg 1969, Dickman et al. 1991, Trejo

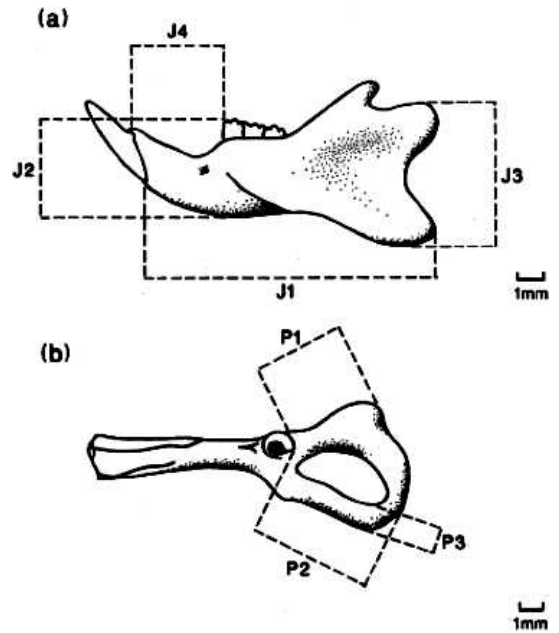


Figure 1. Measurements of jaw and pelvis of *R. r. diardii*. Measurements are defined as (a) jaw: J1 = dentary length excluding incisors; J2 = dentary height at, and including first molar; J3 = maximum dentary height, excluding coronoid process; J4 = diastema length; and (b) pelvis: P1 = ischium length from acetabular rim to the ischial tuberosity; P2 = maximum pubis length from acetabular rim; P3 = pubis width at thinnest point (drawings from Figure 1 in Dickman et al. 1991).

and Guthmann 2003) in the reference specimens. For definitions of bone dimensions see Figure 1. The three pelvic measurements were used to separate male and female reference specimens for *R. r. diardii* by plotting pubis width against the ratio of pubis length : ischium length (Dunmire 1955, Brown and Twigg 1969, Dickman et al. 1991). Following Trejo and Guthmann (2003), these data from *R. r. diardii* were then analyzed with discriminant function analysis to distinguish the sexes. The threshold value to separate males and females was calculated based on the average between the two mean z values (for males and females) obtained from the discriminant function. There were not enough bones from the other rat species for this analysis. We also recorded the lengths of the skull, femur, scapula, tibio-fibula, humerus, and pelvis.

We obtained body mass estimates of *R. r. diardii* found in pellets from a regression model of the natural logarithm of live body mass against the nat-

Table 1. Numbers and live body masses (g) of captured *Rattus* spp.

| SPECIES | BODY MASS ($\bar{X} \pm \text{SE}$; MAXIMUM AND MINIMUM VALUES IN PARENTHESES) | | | | | |
|------------------------------|--|-------|---------------------------------|-----|---------------------------------|-----|
| | OVERALL | n^a | MALE | n | FEMALE | n |
| <i>Rattus rattus diardii</i> | 135.4 \pm 1.6 (21.0–280.0) | 829 | 125.9 \pm 2.2 (25.0–215.0) | 392 | 144.2 \pm 2.3 (21.0–280.0) | 426 |
| <i>Rattus argentiventer</i> | 130.2 \pm 2.7 (12.0–282.0) | 409 | 132.1 \pm 4.5 (20.0–282.0) | 180 | 128.7 \pm 3.3 (12.0–272.0) | 226 |
| <i>Rattus tiomanicus</i> | 112.8 \pm 5.6 (38.0–184.0) | 45 | 109.0 \pm 6.5 (47.0–153.0) | 25 | 124.9 \pm 9.4 (62.0–184.0) | 19 |
| Others | | 9 | | | | |
| Total | | 1292 | | 597 | | 671 |

^a The numbers of male and female rats were less than the total numbers captured due to the exclusion of some individuals that escaped before they could be sexed.

ural logarithms of bone lengths from reference specimens (Morris 1979, Yalden 2003). Application of a logarithmic transformation allowed for a linear allometric relationship (Bailey 1959). For each skeleton set retrieved from a pellet, only one of each set of paired bones, the left bone in most cases, was used in the regression models for body mass estimation. All mean values of measurements are presented with standard errors. Eight bone sets from the reference collection were excluded from the above regression model and later used to validate the discriminant function model. Except for those based on diastema and pelvis lengths, all mean values of the predicted body masses were within 1 SE of the actual body masses.

To assess whether there was differential predation on sex classes, we used a *G*-test to compare the proportions of the sexes of the rats captured and those identified from pellets. We employed a Kolmogorov-Smirnov test to compare the body masses of prey estimated from bones obtained from pellets and those measured from captured rats, to assess if there was differential predation on prey sizes by the owls. A Wilcoxon signed ranks test was used to measure the reliability of the estimates by comparing the body masses estimated from 25 dentary and femur lengths obtained from the same pellets. We used a Mann-Whitney *U*-test to compare the body masses of prey between the owls' breeding and non-breeding seasons, and a *G*-test to compare the proportions of prey species identified from pellets with those of the rats captured. We employed nonparametric tests in this study because of the small number of pellets collected and the consequent departures of the data from the assumptions of parametric tests.

RESULTS

We collected 203 pellets, from which all bones retrieved were those of small mammals. Rodent bones were found in 95.1% of the pellets; other bones were from the order Soricomorpha (shrews). The species identified from pellets were in the same rank order of abundance, and there was no significant difference in proportions as compared to the live captures ($G = 2.243$, $P = 0.326$). Ninety-one (67.4%) skeletons were identified as *R. r. diardii*, which was the predominant species captured in the area (64.2% in Table 1), whereas 33 (24.4%) were *R. argentiventer* (31.7% in Table 1), four (3.0%) were *R. tiomanicus* (3.5% in Table 1) and seven (5.2%) were the musk shrew *Suncus murinus*, which was never trapped. Among the live captures that included both juveniles and adults, there were no significant differences between body masses of males and females for *R. argentiventer* (Mann-Whitney $Z = -0.812$, $P = 0.417$) and *R. tiomanicus* ($Z = -1.494$, $P = 0.135$). However, female *R. r. diardii* captured were significantly heavier than males ($Z = -6.234$, $P < 0.001$; Table 1). For the euthanized *R. r. diardii*, there were no significant differences between the sexes for all bone measurements, except for pubis length, pubis width, and pelvis length (Table 2).

We classified the remains from the 44 pellets as 28 females (63.6%) and 16 males (36.4%) based on the discriminant function analysis, which did not differ from the proportions of the sexes among individuals captured (52.1% females, 47.9% males; $G = 2.272$, $P = 0.132$). The discriminant function obtained for *R. r. diardii* was $z = 2.842$ (pubis width) + 4.751 (pubis length : ischium length) - 10.982 (with mean $z = -0.294$ for females; mean $z = 0.587$ for males; threshold of 0.147; an overall correct clas-

Table 2. Bone measurements (mm) from euthanized *Rattus rattus diardii* and results of Mann-Whitney *U*-test.

| TYPE OF BONES | MALE | | FEMALE | | MANN-WHITNEY <i>U</i> | |
|---------------------|------------------|----------|------------------|----------|-----------------------|----------|
| | $\bar{X} \pm SE$ | <i>n</i> | $\bar{X} \pm SE$ | <i>n</i> | <i>Z</i> | <i>P</i> |
| Jaw | | | | | | |
| Dentary length | 19.66 ± 0.27 | 37 | 19.74 ± 0.25 | 68 | -1.409 | 0.159 |
| Dentary height | 7.39 ± 0.13 | 37 | 7.42 ± 0.11 | 67 | -0.706 | 0.480 |
| Max. dentary height | 10.24 ± 0.20 | 37 | 10.24 ± 0.15 | 68 | -0.661 | 0.509 |
| Diastema length | 5.68 ± 0.11 | 37 | 5.76 ± 0.09 | 68 | -0.788 | 0.431 |
| Pelvis | | | | | | |
| Pubis length | 13.02 ± 0.23 | 34 | 14.00 ± 0.18 | 61 | -3.649 | <0.001 |
| Pubis width | 2.17 ± 0.08 | 36 | 1.71 ± 0.03 | 64 | -4.780 | <0.001 |
| Ischium length | 11.32 ± 0.27 | 37 | 11.38 ± 0.18 | 64 | -0.648 | 0.517 |
| Skull | 40.68 ± 0.81 | 24 | 39.84 ± 0.98 | 41 | -0.170 | 0.865 |
| Femur length | 29.11 ± 0.81 | 37 | 28.66 ± 0.60 | 68 | -0.329 | 0.742 |
| Humerus | 22.14 ± 0.51 | 37 | 21.83 ± 0.38 | 67 | -0.438 | 0.661 |
| Tibio-fibula length | 32.98 ± 0.68 | 37 | 32.06 ± 0.53 | 68 | -1.342 | 0.180 |
| Pelvis length | 33.00 ± 0.92 | 33 | 34.46 ± 0.42 | 60 | -2.145 | 0.032 |
| Scapula length | 20.06 ± 0.47 | 36 | 20.41 ± 0.34 | 66 | -0.904 | 0.366 |

sification of 70.4%). For the estimation of prey size, we selected the equations obtained from dentary ($\log w_i = -5.863 + 3.604 \log x_{\text{dentary1}}$; $r^2 = 0.858$, $t = 22.888$, $P < 0.001$) and femur ($\log w_i = -1.924 + 2.020 \log x_{\text{femur}}$; $r^2 = 0.845$, $t = 21.802$, $P < 0.001$) lengths based on r^2 values. Predicted body masses using 62 dentary and 84 femur measurements from pellets ranged from 30.9–261.9 g (mean = 125.0 ± 7.0 g) and 16.2–224.4 g (mean = 113.2 ± 9.0 g), respectively; we found no significant difference between the distributions of body masses estimated from dentary and femur bones from pellets and those measured from the actual rats captured (Kolmogorov-Smirnov *Z* statistic = 0.769, $P = 0.596$). There was no significant difference between body masses estimated using 25 dentary and femur lengths obtained from the same pellets (Wilcoxon signed ranks test, $Z = -1.520$, $P = 0.128$).

Ninety-eight pellets were collected during breeding months (November–February), and 105 collected during nonbreeding months (March–October). For all pellets with *R. r. diardii* and in which lower jaws, femurs, or both were present, the predicted body masses of rats did not differ significantly between the breeding (mean = 143.3 ± 7.3 g) and nonbreeding periods (122.0 ± 9.8 g; Mann-Whitney test, $Z = -1.148$, $P = 0.251$).

DISCUSSION

Differential predation by Barn Owls has been demonstrated in several studies, with owls preying

either on larger (Derting and Cranford 1989, Bellocq 1998) or smaller prey (Colvin and McLean 1986, Leonardi and Dell'Arte 2006, Granjon and Traoré 2007) than expected based on availability. In paddy fields, Malaysian Barn Owls preyed mostly on adult rats, although juveniles were also taken when available (Hafidzi and Na'im 2003a). In contrast, in our study Barn Owls did not preferentially select size or sex classes of prey, at least for *R. r. diardii*. There was also no significant difference in prey size selection between the breeding and nonbreeding seasons of the owls, a result which differed from that of Bellocq (1998), who found that Barn Owls selected large prey when their abundance was high during the breeding season.

Our results indicated that Barn Owls in oil palm plantations preyed primarily on small mammals, particularly rodents, whose remains were found in 95.1% of all pellets collected. The owls fed largely on *R. r. diardii*. Because there is no information on the probability of capture of different rat species, we were unable to confirm that *R. r. diardii* was the predominant species in the study area, although this was suggested by our trapping data and by previous trapping at the same plantation (A. Mohd Ahdly pers. comm.). In addition, warfarin has been used for many years in routine rat control at our study site and it is thought that in treated areas *R. r. diardii* tends to replace *R. tiomanicus*, which is normally more common in oil palm plantations (M. Hafidzi pers. comm.). The reasons for this

change in species remain unknown (Wood and Chung 2003), although it has been suggested that an underlying pleiotropic cost from the rapid evolution of resistance reduces the competitiveness of *R. tiomanicus* (Corley and Tinker 2003, Wood and Chung 2003).

Nonselective predation by Barn Owls may be attributable to a lack of differences in the vulnerability of different classes of prey (Longland and Jenkins 1987, Vassallo et al. 1994). Without information on movement patterns of *R. r. diardii*, we cannot determine whether the nonselective predation by Barn Owls at our site was due to the ranging behavior or social structure of the prey, which may in turn lead to a nonrandom distribution of dominant and subordinate individuals in an area. Differential vulnerability of prey classes may also be related to habitat conditions (Trejo and Guthmann 2003). In our study, nonselective predation by Barn Owls may be attributable to the open cover conditions (Duckett and Karuppiyah 1990) of the oil palm plantation, which is regularly weeded to remove competing vegetation. As a consequence, all prey classes may have occupied similarly open habitats, which may have made them equally vulnerable to predators.

In most studies that have shown differential predation by Barn Owls, there were seasonal differences in prey choice, and prey-switching behavior was associated with energy efficiency (Colvin and McLean 1986), as predicted by optimal foraging theory (Stephens and Krebs 1986). In our study population, the owls may not have had difficulty maintaining a high level of energy intake year-round as rats were abundant and bred year-round. It is unlikely that the owls would switch prey species or groups, as documented elsewhere (Morton and Martin 1979, Tores et al. 2005), because rodent pest species dominated the oil palm plantation, as demonstrated by the capture rates in our study. Due to small sample sizes, data on both pellets and trapped samples were pooled across all trapping sessions for all analyses. This may have obscured any seasonal changes in the dietary preferences of the owls. However, comparison of predicted body masses of prey between breeding and nonbreeding seasons provided no evidence of the presence of seasonal effects on the selection of prey according to body mass. Because all reference specimens used to develop the regression models for body mass estimation were obtained from one trapping session, it is possible that the predicted body mass may not be rep-

resentative of the live mass of rats in another season due to seasonal changes in body masses of rats. We attempted to address this issue by collecting pellets over several months during both breeding and nonbreeding seasons.

Although our study did not demonstrate a clear selection of prey by sex classes, we noted that the proportions of females for *R. r. diardii* captured and those identified from pellets were 52.1% and 63.6%, respectively, suggesting a potential selection although no statistically significant difference was found in our study. We suspected that the small sample size derived from the pellet sample may have confounded this comparison. Hence, we suggest that a further study with a larger sample of pellets be conducted.

This study corroborated the feasibility of using pelvic bones to identify the sex of rats and of other bones to estimate the body size of prey. Measurements taken on several pelvic dimensions have shown promise for identifying the sex of Rodentia (Dunmire 1955). We found a good separation of the sexes based on pelvic measurements, as have others for various rodent species (Dunmire 1955, Brown and Twigg 1969). However, some overlap occurred and may have been due to misidentifications of a few non-parous females as juvenile males. Male *R. rattus* typically develop scrotal testes at body mass of 60–100 g (Aplin et al. 2003), and below this mass range it can be difficult to reliably identify the sex of individuals (Brown and Twigg 1969).

Our study also demonstrated the utility of dentary and femur lengths for body mass prediction. With respect to the lower jaw bone, we found that dentary length was the best predictor of body mass, which differed from the use of diastema length by Halle (1988). It should be noted that the body mass distribution of prey individuals was based only on pellets in which both lower jaw (from which dentary length was taken) and femur bones were present, as the lack of skulls or broken skulls in half of the pellets caused difficulty in identifying prey species.

Although we did not demonstrate selective predation by Barn Owls, the owls are common in oil palm plantations (Duckett and Karuppiyah 1990) and given their apparent preference for rodents, it may be cost-effective to facilitate ongoing biological control involving owls rather than to implement regular poison baiting. Future research should use experiments to (a) evaluate whether Barn Owls are more effective than chemical treatments at removing rodent pests, and (b) determine whether a greater

density of Barn Owls would enhance their effectiveness as a biological control agent of pest rodents in oil palm plantations.

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