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Distribution, seasonal use, and predation of incubation mounds of Orange-footed Scrubfowl on Komodo Island, Indonesia

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ABSTRACT. Megapodes are unique in using only heat from the environment, rather than body heat, to incubate their eggs as well as the precocious independence of their chicks on hatching. Of 22 recognized species of megapodes, 9 are listed as threatened due to factors including habitat loss and fragmentation, and predation on eggs and chicks. Orange-footed Scrubfowl (*Megapodius reinwardt*) are conspicuous components of the Oriental/Austral avifauna that inhabit the monsoon forests of the Lesser Sunda chain of islands in Indonesia. We examined the abundance, patterns of distribution, physical characteristics, seasonal activity, and predation risk of incubation mounds of Orange-footed Scrubfowl on Komodo Island in eastern Indonesia. We surveyed 13 valleys on Komodo Island from April 2002 to January 2005 and located 113 tended and 107 untended incubation mounds. Densities of scrubfowl mounds in our study were similar to that reported by investigators during the 1970s, suggesting little change in the scrubfowl population since then. Most scrubfowl mounds were on sandy or loamy soils in open monsoon forest with little overhead shade, and placement of mounds in such areas may ensure adequate temperatures for egg incubation. Although some mounds were tended during all months, mound use peaked during the late wet season in March and, during the dry season (April–November), only a few mounds were tended. Komodo dragons (*Varanus komodoensis*) and wild pigs (*Sus scrofa*) were the primary predators of scrubfowl eggs, with no indication of egg predation by humans. The valley with the largest number of untended mounds in our study also had the largest number of active Komodo dragon nests. Such results suggest the possibility of some effect of Komodo dragons on scrubfowl numbers, but additional study is needed.

SINOPSIS. **Distribución, uso temporal y depredación de los montículos incubadores del *Megapodius reinwardt* en la isla de Komodo, Indonesia**

Los Megadopodos son únicos al usar calor del ambiente, en vez de calor corporal, para incubar sus huevos, y que sus polluelos nidífugos son independientes después de la eclosión. De las 22 especies de Megapodos reconocidas, nueve están en la lista de especies amenazadas debido a factores como pérdida y fragmentación del hábitat y depredación de huevos y polluelos. *Megapodius reinwardt* es un componente conspicuo de la avifauna Oriental/Austral que vive en los bosques monzones en las islas de las Sundas Menores en Indonesia. Examinamos la abundancia, patrones de distribución, características físicas, actividades temporales y riesgo de depredación en los montículos incubadores de *M. reinwardt* en la isla de Komodo en el este de Indonesia. Examinamos 13 valles en la isla de Komodo entre Abril 2002 y Enero 2005 y localizamos 113 montículos incubadores atendidos y 107 que no estaban siendo atendidos. Las densidades de montículos de *M. reinwardt* en nuestro sitio de estudio fueron similares a los reportados por investigadores en la década de los ‘70, lo cual siguiere pocos cambios en la población de *M. reinwardt* desde entonces. La mayoría de los montículos de *M. reinwardt* se encontraron en suelos arenosos o margosos en bosques monzones abiertos, con poca cobertura de vegetación, y la localización de los montículos en estas áreas posiblemente aseguran temperaturas adecuadas para la incubación de los huevos. A pesar de que algunos montículos estuvieron atendidos durante todos los meses, el pico de uso de los montículos ocurrió durante el final de la temporada de lluvias en Marzo, y durante la temporada seca (Abril–Noviembre) solo algunos montículos estuvieron atendidos. Los dragones de Komodo (*Varanus komodoensis*) y los cerdos salvajes (*Sus scrofa*) fueron los principales depredadores de los huevos de *M. reinwardt*, y no hubo indicio de depredación por humanos. En nuestro estudio el valle con

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los mayores números de montículos desatendidos tenía el mayor número de nidos activos de dragones de Komodo. Este resultado sugiere la posibilidad de algún efecto de los dragones de Komodo en los números de *Megapodius reinwardt*, pero estudios adicionales son requeridos.

Key words: Indonesia, Komodo Island, *Megapodius reinwardt*, nest distribution, Orange-footed Scrubfowl, predation risk

Megapodes (Megapodiidae) are unique in their use of heat derived solely from the environment, rather than body heat, to incubate their eggs, burying them in substrates heated by solar radiation, geothermal activity, or microbial decomposition (Frith 1956, Jones and Birks 1992). The chicks that emerge from these incubation sites are the most advanced of any bird in terms of their behavior and physiological capabilities (Jones et al. 1995). Of the 22 recognized species of Megapodes, 9 are listed as threatened due to factors including habitat loss and fragmentation, and predation on eggs and chicks (Jones and Birks 1992, Jones et al. 1995, Sankaran 1995, Dekker et al. 2000). Reliably assessing the ongoing effects of this disturbance and determining the conservation status of many megapodes have been difficult due to the lack of information for most species (Jones et al. 1995) and a paucity of studies documenting changes in abundance over time (Priddel and Wheeler 2003, Gorog et al. 2005). Two recent IUCN megapode action plans have resulted in the assignment of all megapode species to broad Mace-Lande/IUCN Red List categories and have considerably improved our knowledge of this diverse group, even if the conservation status of most of the threatened megapodes is yet to improve (Dekker and McGowan 1995, Dekker et al. 2000). The stated focus of the most recent action plan is long-term conservation studies and the active involvement of the local community and local authorities (Dekker et al. 2000).

Between the islands of Sumbawa and Flores in eastern Indonesia lies Komodo National Park (KNP). KNP covers 1817 km^2 of land and sea, and includes three major islands (Komodo, Rinca, and Padar) and numerous smaller islands, ranging up to 336 km^2 in size. Orange-footed Scrubfowl (*Megapodius reinwardt*) are conspicuous components of the mixed Oriental/Austral avifauna that inhabit mainly the monsoon forests (tropical dry deciduous forest) along the Lesser Sunda chain of the larger islands (Monk et al. 1997). Orange-footed Scrubfowl also occur in beach forest, low-stature, scrubby vegetation, mangrove forest, savannah woodland, and primary rainforest in lowlands and hills (Coates and Bishop 1997). Indonesia supports all but 5 of the 22 species of megapodes, including the threatened Phillipine Megapode (*M. cumingii*) and the Maleo (*Macrocephalon maleo*; MacKinnon 1981, Jones and Birks 1992, Dekker and McGowan 1995, Dekker et al. 2000, Butchart and Baker 2002, Sinclair et al. 2002, Gorog et al. 2005). Orange-footed Scrubfowl, considered at a low risk of extinction, have an extensive geographical range over which there is surprisingly little geographical variation, possibly indicating more gene flow between island populations than for other species (Jones et al. 2005). However, in some areas they face the **Q1** same threats as other megapodes. Information about the number of incubation mounds and the habitat characteristics that influence their distribution is needed to facilitate informed decisions regarding scrubfowl management and conservation in KNP. Further, Orange-footed Scrubfowl mounds are an important resource for female Komodo dragons (*Varanus komodoensis*) because up to 70% of females in KNP oviposit in megapode incubation mounds (Jessop et al. 2004). Thus, knowledge of the nesting ecology of scrubfowl is also important for the management of the high conservation status Komodo dragon, listed as vulnerable under the IUCN Red list criteria due to its extremely limited distributional range. Our objective, therefore, was to determine the distribution and abundance of megapode mounds on Komodo Island. In addition, we examined the characteristics of mound sites to better understand the habitat requirements of Orange-footed Scrubfowl and documented predation events.

METHODS

Nest surveys. Field work was conducted on Komodo Island (8°35′40″ S, 119°25′51″ E; 336 km^2), the largest island in KNP, eastern Indonesia. KNP is home to several thousand human inhabitants, including approximately

1500 people that live in Komodo village on Komodo Island. Surveys were conducted from April to October 2002 to locate and describe incubation sites, and we also conducted 2-d surveys approximately every 2 mo from March 2004 to January 2005 to monitor nesting activity and predation. Surveys in 2002 were conducted in concert with those undertaken for Komodo dragon nesting sites (Jessop et al. 2004) and covered the most suitable habitat for Orange-footed Scrubfowl. We surveyed 13 valleys, adjacent slopes, and coastal flats that comprised mostly open deciduous forest (dry monsoon forest), closed forest, or savannah woodlands (Fig. 1). To inventory incubation mounds, intensive focal sampling was used. Sampling was conducted across consecutive transect grids with multiple observers (N = 5–8) walking at 25-m intervals along parallel transects. The length and number of transects in each valley were determined by topography.

Orange-footed Scrubfowl build the largest incubation mound of any megapode (Jones et al. 1995, Palmer et al. 2000). Mounds are volcano-shaped and have been recorded in continual use for over 40 yr (Banfield 1913) and several pairs may use a single mound simultaneously (Crome and Brown 1979). Eggs are laid in chambers within mounds following temperature testing by the female, and chambers are then carefully covered with vegetation (Crome and Brown 1979). For each mound located, we recorded the location, elevation, status (tended or untended), overhead vegetation cover (0–25, 26–50, 51–75, or 76–100%), adjacent vegetation type (open forest, closed forest, savanna, or grasslands), and soil type (loamy, sandy, rocky, or gravelly). Structural characters of each mound were also recorded, including length, width, height, and the number of chambers excavated in each mound.

Tended scrubfowl mounds were those used for breeding during that breeding season and were distinguished from untended mounds by evidence of recent digging, incorporation of new leaf litter, and, in some instances, the presence of adults at a nest or the presence of their tracks. Untended mounds were those not being used in that breeding season and ranged from mounds with egg chambers containing old leaf litter to flattened mounds with no evidence of activity and covered in grass. The density of tended Orange-footed Scrubfowl mounds was calculated by dividing the total nest number for each category by the area searched as calculated by shape polygons using Arcview 3.1 (Environmental Systems Research Institute, Inc., Redlands, California). As an index of nest dispersion, the mean nearest-neighbor measurement was calculated within valleys as the average distance to the closest neighbor from each nest in a survey location.

Predation index. Due to the difficulty of measuring egg predation directly, we used an index of predation based on the presence of fresh excavations into the egg chambers of tended scrubfowl mounds and calculated the percentage of nests with fresh excavations for each survey. Predators were identified by their tracks and associated burrowing as either Komodo dragons or wild pigs (*Sus scrofa*). During routine monitoring, we were also able to determine if humans had attempted to harvest eggs.

Statistical analysis. For categorical data, χ^2 tests were used to assess whether there were significant differences in the proportion of variables against expected values. Parametric tests, including t-tests and analysis of variance, were used to examine possible differences between means for continuous data that met the assumptions of normality and homogeneity of variance. Continuous data that did not meet these assumptions were log-transformed. Linear and polynomial regressions were also performed to assess significant trends. For all statistical tests, significance was accepted at $P < 0.05$. Values are presented as means ± 1 SD.

RESULTS

Abundance and distribution. We found 113 tended Orange-footed Scrubfowl incubation mounds in 9 of 13 valleys surveyed on Komodo Island (Table 1, Fig. 1). There was a significant positive relationship between valley area and the number of mounds (linear regression: $F_{1,10} = 24.9$, $P = 0.001$, $r^2 = 0.71$). The greatest number of mounds was found in Loh Liang ($N = 44$), Loh Sebita ($N = 19$), Loh Lawi ($N = 18$), and Loh Wau ($N = 15$), with the highest density of tended mounds in Loh Wau (6.3/km^2; Table 1). In some valleys, there were no tended mounds (Loh Boko, Loh Baes, Loh B'oh, and Loh Seloka).

We also located 107 untended mounds. The distribution of these mounds was similar to that

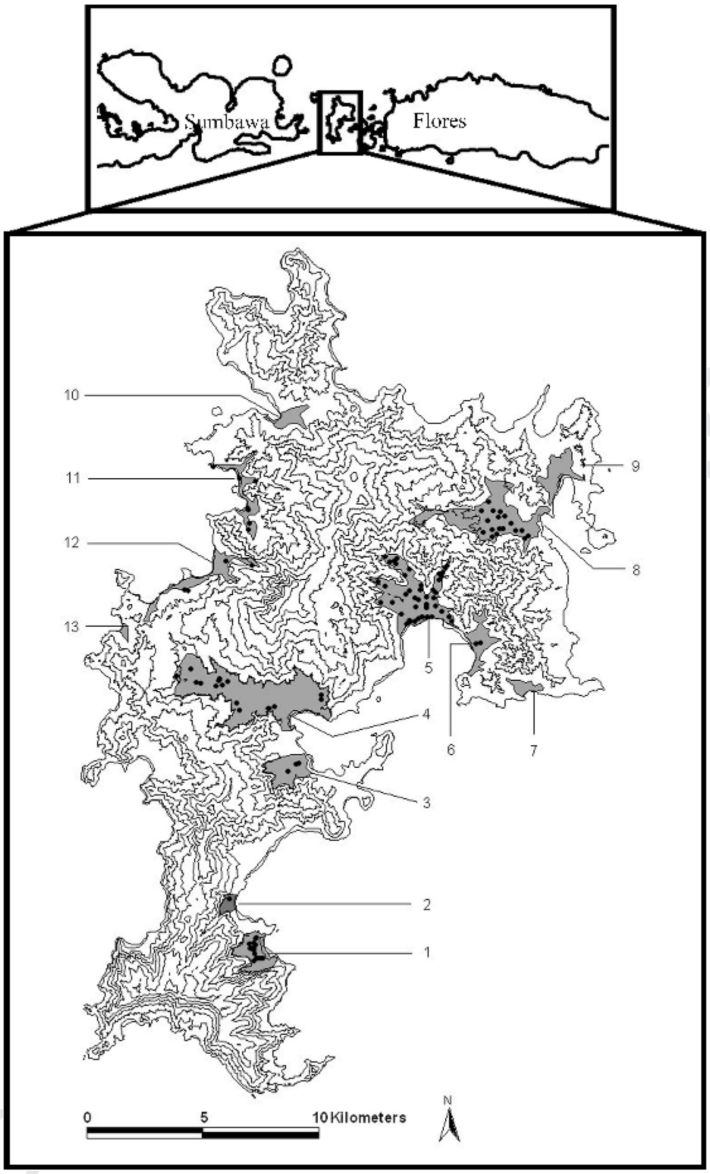

Fig. 1. Topographical map indicating the distribution of tended Orange-footed Scrubfowl incubation mounds on Komodo Island within Lesser Sunda region (inset), Indonesia. Shaded areas indicate the valley area covered in surveys for Scrubfowl mounds. Filled circles indicate tended incubation mounds. Valleys are numbered 1–13 and represent the following locations: (1) Loh Wau, (2) Loh Gong, (3) Loh Pinda, (4) Loh Lawi, (5) Loh Liang (6) Loh Kubu, (7) Loh B'oh, (8) Loh Sebita, (9) Loh Baes, (10) Loh Boko, (11) Loh Wenci, (12) Loh Srikaya, and (13) Loh Seloka. The scale of elevation of contour lines is units of 100 m.

of tended mounds, with most in Loh Sebita ($N = 36$), Loh Liang ($N = 35$), and Loh Lawi ($N = 20$; Table 1). The highest density of untended mounds was 3.4/km^2 in Loh Liang (Table 1).

For tended mounds, the mean nearest-neighbor distance (an index of nest dispersion) differed among valleys ($F_{6,96} = 4.4$, $P = 0.001$). Mounds in Loh Wau exhibited the least amount of dispersion (0.10 ± 0.05 km).

Table 1. Summary data of incubation mound occurrence on Komodo Islands with valley location, survey area in each valley (Area), total number of tended mounds (No. TM), total number of untended mounds (No. UM), mean distance to the nearest neighboring tended mound (Mean NNTM), mean distance to the nearest neighboring untended mound (Mean NNUM), the density of tended mounds in each valley (DTM), and the density of untended mounds in each valley (DUM).

Location	Area (km^2)	No. TM	No. UM	Mean NNTM ± SD (km)	Mean NNUM ± SD (km)	DTM (nest/km^2)	DUM (nest/km^2)
Loh Liang	10.31	44	35	0.22 ± 0.10	0.21 ± 0.13	4.27	3.39
Loh Kubu	3.21	2	0	0	0	1.66	0
Loh Lawi	11.36	18	20	0.41 ± 0.56	0.12 ± 0.11	1.58	1.76
Loh Sebita	10.84	19	36	0.27 ± 0.12	0.16 ± 0.11	1.75	3.32
Loh Srikaya	5.75	4	6	0.64 ± 0.59	0.38 ± 0.41	0.69	1.04
Loh Wenci	4.62	7	7	0.57 ± 0.45	0.10 ± 0.09	1.37	1.37
Loh Boko	3.37	0	0	0	0	0	0
Loh Baes	3.83	0	0	0	0	0	0
Loh Pinda	2.52	3	1	0.23 ± 0.18	0	1.19	0.40
Loh Wau	2.39	15	2	0.10 ± 0.05	0.94 ± 0.01	6.28	0.84
Loh B'oh	2.04	0	0	0	0	0	0
Loh Seloka	1.15	0	0	0	0	0	0
Loh Gong	0.42	1	0	0	0	2.38	0
Total/mean	62.17	113	107	–	–	1.82	1.7

At the other extreme, the mean nearest-nest measurements were 0.64 ± 0.59 km in Loh Srikaya and 0.57 ± 0.45 km in Loh Wenci. We found no difference in the mean nearest-neighbor distance between tended and untended mounds ($t = 0.6$, $P = 0.35$). Untended scrubfowl mounds tended to be higher above sea level (mean = 36.4 ± 17.6 m) than tended mounds (mean = 32.9 ± 3.6 m), but the difference was not significant ($t = 1.7$, $P = 0.089$).

Mound characteristics. Mounds were not randomly located with respect to overhead cover ($\chi^2_3 = 42.7$, P < 0.001), with 47% of tended mounds having ≤25% overhead cover, 28% with 26–50% cover, 19% with 51–75% cover, and 6% with 76–100% overhead cover. Most mounds were located in open monsoon forest (95%), with 3% in closed monsoon forest and 2% in savannah woodland. Orange-footed Scrubfowl mounds were mainly located on loamy (70%) or sandy (27%) soils, with only a few built on soil with rocks or gravel (3%). Most (81%) untended mounds were in open monsoon forest, with 9% in ecotones on the edge of open monsoon forest, 5% in closed monsoon forest, and the remaining 5% located in foredune forest, savannah woodlands, or savannah grasslands.

For tended mounds ($N = 124$), the mean length was 7.4 ± 2.4 m, the mean width was 6.7 ± 2.2 m, the mean height was 0.97 ± 0.36 m, and the mean number of egg chambers was 2.3 ± 1.9. For untended mounds ($N = 107$), the mean length was 6.2 ± 1.2 m, the mean width was 5.6 ± 1.4 m, and the mean height was 0.6 ± 0.25 m. Tended mounds were longer ($t = 3.6$, $P = 0.001$) and taller ($t = 3.5$, $P = 0.001$) than untended mounds, but there was no difference in width ($P > 0.05$).

Seasonal variation in mound use. Tended mounds were recorded during all months. However, mound use was seasonal ($\chi^2_5 = 71.5$, $P < 0.001$), with use beginning in October (late dry season) and peaking during the late wet season in March. During the dry season (April–November), only a few mounds were tended (4.3–6.5%; Fig. 2). This seasonality in nesting activity was correlated with the summer monsoonal rainfall pattern that typically falls from December to March in this region of Indonesia.

Predation. Evidence of mound disturbance indicated that Komodo dragons (claw and tail marks) and, less often, pigs (hoof and snout digging) were the primary predators of scrubfowl eggs. The risk of predation varied between 0 and 17.3% of tended mounds disturbed per survey

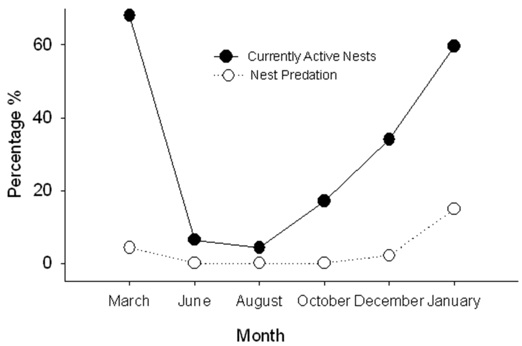

Fig. 2. Percentage of tended incubation mounds found during each sampling trip, indicating seasonal variation in nesting activity of Orange-footed Scrubfowl and the incidence of egg predation recorded during sampling trips during 2004–2005 on Komodo Island.

and tracked seasonal nesting activity ($\chi^2_5 = 43.2$, $P < 0.001$; Fig. 2). On three occasions, Komodo dragons were observed excavating egg chambers. We found no evidence that humans collected scrubfowl eggs in KNP.

DISCUSSION

Abundance and distribution. We located 113 tended and 107 untended mounds on Komodo Island, with densities ranging from 0 to 6.3 tended mounds per km^2 and 0.4 to 3.4 untended mounds per km^2. Lincoln (1974) reported 23 tended and 19 untended mounds in an area of about 2.5 × 1.5 km along the coast of Komodo Island, or about 6.1 tended and 5.1 untended mounds per km^2. Direct estimates of the population size based on the number of tended mounds cannot be made because Orange-footed Scrubfowl share mounds and tend multiple mounds in the same year (Crome and Brown 1979). However, the density of scrubfowl mounds in our study was similar to that reported by Lincoln (1974), suggesting little change in the scrubfowl population over the past several decades.

Reasons for differences in mound densities between valleys (other than valley size), as well as differences in the ratio of tended to untended mounds, are unclear. However, several factors relating to habitat quality (i.e., forest area and complexity) and, ultimately, food availability and access to water could influence scrubfowl densities (Root 1998, Siikamaki 1998). For example, on Nicobar Island, Sankaran (1995) found fewer nests of Nicobar Scrubfowl (*M. nicobariensis*) in habitats where there was less vegetation available for building nests. The number of mounds (tended and untended) in each valley in our study was similar, with the exception of Loh Liang where we found 45 tended mounds and only 35 untended mounds. Factors contributing to the large number of tended mounds in Loh Liang may include the valley's large area and the presence of relatively large tracts of closed forest that may provide scrubfowl with needed resources.

Mound site preferences. We found that Orange-footed Scrubfowl constructed mounds primarily on sandy or loamy soils in open forest areas with a minimum of overhead cover. Similar associations of incubation sites with sandy surface soils and sandy substrate have been reported on Komodo Island and in the Northern Territory of Australia (Lincoln 1974, Bowman et al. 1994). Most mounds of Orange-footed Scrubfowl in our study were in unshaded areas in open forest. In contrast, mounds of Philippine Megapodes in North Sulawesi were located at the base of large dead trees in less disturbed areas with a relatively high and closed canopy and a less dense understory (Sinclair et al. 2002). Closed canopies likely protect the mounds of Philippine Megapodes from desiccation and fluctuations in air temperature (Sinclair et al. 2002). Decomposition of litter was found to be the primary source of heat for Orange-footed Scrubfowl mounds in monsoon and regeneration forests, whereas both solar radiation and microbial decomposition contributed to the heat of the mounds in the sandy coastal vine thicket (Palmer et al. 2000). Placement of mounds in open areas with sandy or loamy soil may ensure adequate temperatures for egg incubation, and nearby shrubs may enhance the survival of hatchlings likely to be under considerable predation pressure (Goth and Vogel 2002).

Jessop et al. (2004) found that up to 61% of female Komodo dragons used scrubfowl mounds for nesting, and they typically selected Megapode incubation mounds more exposed to sunlight. The mounds of most scrubfowl in our study were also exposed to sunlight, presumably to accelerate egg incubation. Despite the use of mounds by dragons and scrubfowl, the low density of female Komodo dragons on Komodo Island likely precludes competition via displacement of scrubfowl from their incubation sites.

Mound characteristics. The dimensions of mounds in our study were similar to those reported previously for Orange-footed Scrubfowl (Lincoln 1974), and nest mounds (14 tended and 10 untended) of Micronesian Megapodes (*Megapodius laperouse senex*) in the Palau Islands of western Micronesia were also of similar size (Wiles and Conry 2001). We found either a similar number of or fewer untended mounds than tended mounds in every valley except for Loh Sebita, where there were only 19 tended mounds compared to 36 untended mounds. The large number of untended mounds suggests that the number of breeding pairs of megapodes in the Loh Sebita Valley may have recently declined. Interestingly, of all surveyed valleys, this valley also had the largest number of active Komodo dragon nests ($N = 9$) on Komodo Island, and six of those nests were in scrubfowl mounds (Jessop et al. 2004.). In addition, the next highest number of Komodo nests in a valley ($N = 5$) was in Loh Lawi Valley where there were fewer tended ($N = 18$) than untended ($N = 20$) scrubfowl mounds. Although these results suggest the possibility of some effect of Komodo dragons on scrubfowl numbers, further study would be needed to determine if Komodo dragons actually have a negative impact on Orange-footed Scrubfowl.

Predation. The distribution and density of megapodes and the activity status of their mounds could be influenced by Komodo dragons because they prey on both the birds and their eggs (Auffenberg 1981). Predation attributed to Komodo dragons did not exceed 17% of mounds in our study. In addition, scrubfowl eggs take about 2 mo to hatch and multiple clutches are laid throughout the breeding season (Jones et al. 1995), so it is difficult to assess both the number of eggs taken during each predation event and the impact of such predation on the scrubfowl population. Further long-term monitoring is needed to determine overall rates of egg predation and the possible relationship between the availability of alternate prey and rates of egg predation by Komodo dragons.

Villagers on Komodo Island harvested Megapode eggs prior to the establishment of KNP (A. Sahu, KNP ranger, pers comm.), but they apparently no longer do so. During our study, we found no evidence that villagers were either harvesting eggs or killing adult scrubfowl in the park.

Conservation implications. Human encroachment on potential nesting habitat of Orange-footed Scrubfowl on Komodo Island so far appears to be limited. However, with information about the incubation sites and the seasonal profiles of activity for these scrubfowl in KNP, park authorities will now be able to monitor and assess the status of this species in what appears to be a well-protected habitat. The proportion of tended and untended nests may be an indicator for evaluating the population status of this species (Sankaran 1995, Jessop et al. 2004). Annual monitoring of these sites would require relatively less time each year, is fairly inexpensive, and does not require sophisticated equipment or expertise. Hence, this type of monitoring project is well-suited to the funding and technical resources available in KNP.

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