RAFFLES BULLETIN OF ZOOLOGY **64**: 89–97
Date of publication: 13 May 2016
http://zoobank.org/urn:lsid:zoobank.org:pub:FA3361D2-7D70-4771-A150-7AE2C53370F4

Nesting ecology and nest site selection of green-legged partridge

Tiwa Ong-in[1], Andrew J. Pierce[1], George A. Gale[1], Stephen J. Browne[2] & Tommaso Savini[1]

Abstract. The ecology of the hill partridges, comprising the genera *Arborophila* and the recently revived *Tropicoperdix*, is poorly known and field-based studies are required to increase our understanding and facilitate the development of conservation action plans. We examined the nesting ecology and nest site selection of the green-legged partridge (*Tropicoperdix chloropus*) in Khao Yai National Park, northeastern Thailand from 2007 to 2010. Nests were monitored using 24-hour video cameras and habitat characteristics at nest sites and random sites were examined to determine nest site selection. Eighteen nests were found, all on the ground between the buttresses of large trees. Nesting took place during the rainy season (May–September). The average incubation period was 19.2 ± 0.5 SE days (range = 18–20 days, *N* = four nests). Nest survival was 26.7 ± 11.1 SE % (*N* = 16), which was within the range of other galliformes species at the study site. Clutch size was two to four eggs and mean clutch size was 3.19 ± 0.14 SE eggs (*N* = 16); however, clutch size was larger and breeding started earlier (~6 weeks) in the year that precipitation started unseasonably early. Nest predators included macaques (*N* = five nests) and treeshrews (*N* = one nest). The female partridge incubated alone and showed high incubation constancy of 98%. The position of their nests between the buttresses of large trees likely has the potential to serve as concealment from potential predators. Our nest site selection model indicated that green-legged partridge preferred to place nests in an area associated with dense vegetation and higher coverage of small trees, higher density of large trees, and a higher number of woody climber stems. An enhanced understanding of how nest site selection relates to environmental factors will facilitate insight into the ecology of this species and will be beneficial for understanding potential ecological differences between *Arborophila* and those suggested to belong to *Tropicoperdix*.

Key words. Galliformes, *Arborophila chloropus*, *Tropicoperdix chloropus*, nest survival, incubation behaviour, nest predation

INTRODUCTION

The galliform genus *Arborophila* has traditionally consisted of 21 species in Asia (Madge & McGowan, 2002; del Hoyo et al., 2014), with four species listed as Endangered and four as Vulnerable in the IUCN Red List (IUCN, 2014). However, the results of a recent phylogenetic analysis have shown that up to three species are not closely related to the bulk of *Arborophila* and are separable under the genus name *Tropicoperdix* (Chen et al., 2015). All of these partridges in Asia are threatened by hunting and habitat degradation (Keane et al., 2005) and they include some of the most poorly understood Galliformes. Understanding population dynamics, including reproductive behaviour and nest habitat selection, is important for assessing conservation measures for species in the genus *Arborophila* and *Tropicoperdix*, and knowledge about nearly all aspects of their ecology in the wild is lacking (Fuller et al., 2002). The Endangered Sichuan hill-partridge *A. rufipectus* has been most intensively studied and some knowledge has been gained on its ecology in the subtropical forests of southern China; such information can be usefully applied to lesser-known species (Dai et al., 1998; Dai et al., 2009). However, most species in the genera *Arborophila* and *Tropicoperdix* inhabit tropical regions. In particular, the selection of suitable nesting sites is likely to play a fundamental role in determining failure or success of a given breeding attempt (Martin, 1995). As a consequence, nesting success, and consequent population recruitment, can be potentially correlated with several factors, including the microhabitat around the nest, nest height, and/or nest concealment (Jones, 2001; Weidinger, 2002).

The green-legged partridge (*Tropicoperdix chloropus*) is a relatively small galliform (260–350 g) inhabiting dense lowland and sub-montane evergreen forest up to 1,000 m above sea level (Lekagul & Round, 1991; Robson, 2008). Little is known about its behaviour and ecology in the wild, even though it appears to be relatively common and widespread within its range. The species is suspected to be in decline owing to ongoing habitat destruction and unsustainable levels of hunting (BirdLife International, 2013).

We studied the nesting ecology and factors that influence nest site selection of the green-legged partridge. Our objectives were to (1) examine the timing of breeding, incubation period, clutch size and nesting success of green-legged partridge,

---

[1] Conservation Ecology Program, King Mongkut's University of Technology Thonburi, 49 Bangkhuntien-Chaythalay Road, Thakham, Bangkhuntien, Bangkok, Thailand 10150; Email: anatiwa@gmail.com (*corresponding author)

[2] Fauna & Flora International, The David Attenborough Building, Pembroke Street, Cambridge, UK, CB2 3QZ

ISSN 2345-7600 (electronic) | ISSN 0217-2445 (print)

(2) monitor female incubation behaviour, and (3) compare microhabitat variables at nest sites with randomly selected sites to investigate which variables best predicted nest site selection. Finally, we examined the location of nests within home ranges. We predicted that nest sites would be closer to the centre of a home range than to the home range boundaries.

MATERIAL AND METHODS

Study area. Our study was conducted from May 2007 to September 2010 in and around the Mo Singto Long Term Biodiversity Research Plot (hereafter MST, Brockelman et al., 2011) of Khao Yai National Park in northeastern Thailand (14.26°N, 101.22°E). The park covers an area of 2,168 km^2 mainly of seasonally wet evergreen forest (Kitamura et al., 2004). The MST covers an area of 30 ha, with an elevation of 723–817 m. The vegetation is old growth forest, with a small area of 40-year-old secondary forest at the northern edge of the plot (Brockelman et al., 2011). Average annual precipitation is 2,697 mm (range = 2,967–2,297 mm); most rain falls during May–October. Average daily temperature varies annually between 18.7 and 28.3°C, and average humidity ranges from 64.6% during the dry season to 77.1% during the wet season (Savini et al., 2008).

Bird trapping and tagging. We used call playback to attract and catch partridges using mist nets set at ground level (15 mm mesh, 3-shelf mist nets, 12 × 2.75 m) between May 2009 and April 2010. All captured birds were banded with one metal band (7 mm internal diameter), issued by the Department of National Parks, Wildlife and Plant Conservation (DNP), and 2–3 plastic colour bands to allow individual recognition in the field. Nine birds were also fitted with a 10 g backpack-mounted radio-transmitter (green-legged partridge, weighed ≥ 260 g), with an expected battery life of 18 months (Holohil Systems Ltd., Canada).

Nest searching. One green-legged partridge nest was found by chance during studies of other species (Round et al., 2011). During May–August of 2009 and 2010, we searched for partridge nests systematically in the home ranges of seven partridge groups and by relocating radio-tagged birds.

Nest monitoring and nesting success analysis. Once a nest was found, we flushed the adult, if present, to count the eggs and record the nearest large tree position for later monitoring. Nests were checked daily during the laying stage and every 2–3 days during incubation until eggs hatched or the nest failed. At 10 nests we also placed 24-hour surveillance infrared video cameras (Pierce & Pobprasert, 2007) on a small tree ~2–3 m from the nest, well hidden to ensure that the camera did not attract potential predators or otherwise disturb incubating birds. The cameras were attached by cables to a digital video recorder (DVR) fixed 20–25 m from the nest whereby the power source and DVR could be changed without disturbing the nesting birds (Pierce & Pobprasert, 2007). After setting, the cameras ran continuously until the eggs hatched or the nesting attempt failed. We used the resulting video recordings to identify nest predators, to calculate the timing of incubation bouts, and to record female activity including nest defense during incubation. We concluded a nest was successful if we observed eggshells with detached shell membranes following Klett et al. (1986) or adults with young nearby for those nests where cameras were not set. Nest failure was caused solely by predation and was indicated by eggshell fragments surrounding the nest or the eggs having disappeared before the expected hatch date.

A total of 18 nests were found. Two nests were found after they had either fledged or failed and were not used for clutch size or nest success analysis. We modeled the daily survival rate (DSR) of nests in program R using package RMark (Laake & Rexstad, 2008) to build known fate models for program MARK (White & Burnham, 1999). Seven nests with known outcomes and known clutch sizes were used to calculate hatching success (number of eggs hatched divided by total number of laid eggs).

Nest locations. Nesting sites may be located close to range borders to expedite early detection or prevention of intrusions by neighbouring groups (e.g., Hill & Robertson, 1988); thus we examined the location of nests relative to the distance to the boundaries and centres of respective territories. We estimated the home range size of the green-legged partridge by using a 95% minimum convex polygon (MCP; Mohr, 1947). MCPs were defined for each group by using at least 60 independent locations for each radio-tagged bird. In order to increase independence between locations birds were located in the forest at intervals of at least two hours. The centres of the individual home ranges were calculated from all radio-collared locations. Only known home ranges and known individual birds were used to analyse distance from nest to centre and distance from nest to home range boundary. We separated radio-collared locations for each year to estimate home ranges and used the nest in these same years to calculate distance from nest to centre and nest to boundary. We only used nests ($N = 13$) associated with radio-collared birds for this analysis. All analyses were conducted in ArcGIS version 9.3 (ESRI, 2009). The Student's *t*-test was used to compare the mean distance between nest to home range centre and from nest to nearest home range boundary.

Data analyses. For each of 17 nests (one nest from 2007 was excluded due to insufficient vegetation data), habitat features were recorded within a 5 m-radius circular plot centred on the nest (Martin et al., 1997). We made the same measurements at 34 randomly selected sites within the MST plot; the random sites covered all studied territories and were assumed to be representative of the entire area. The locations of random plots were defined by randomly selecting 34 trees, with DBH similar to those used by the partridges as nesting trees, within the MST plot database. Microhabitat at nest and random sites was classified into four categories based on vegetation strata. In each plot, we measured the following habitat variables: DBH (diameter at breast height) of the tree at the base of which birds placed their nest, elevation (m asl), nest tree species, and slope. Vegetation in each plot was classified into four levels based on height: 0.5–1 m, 1–3 m, 3–5 m and > 5 m (Martin et al.,

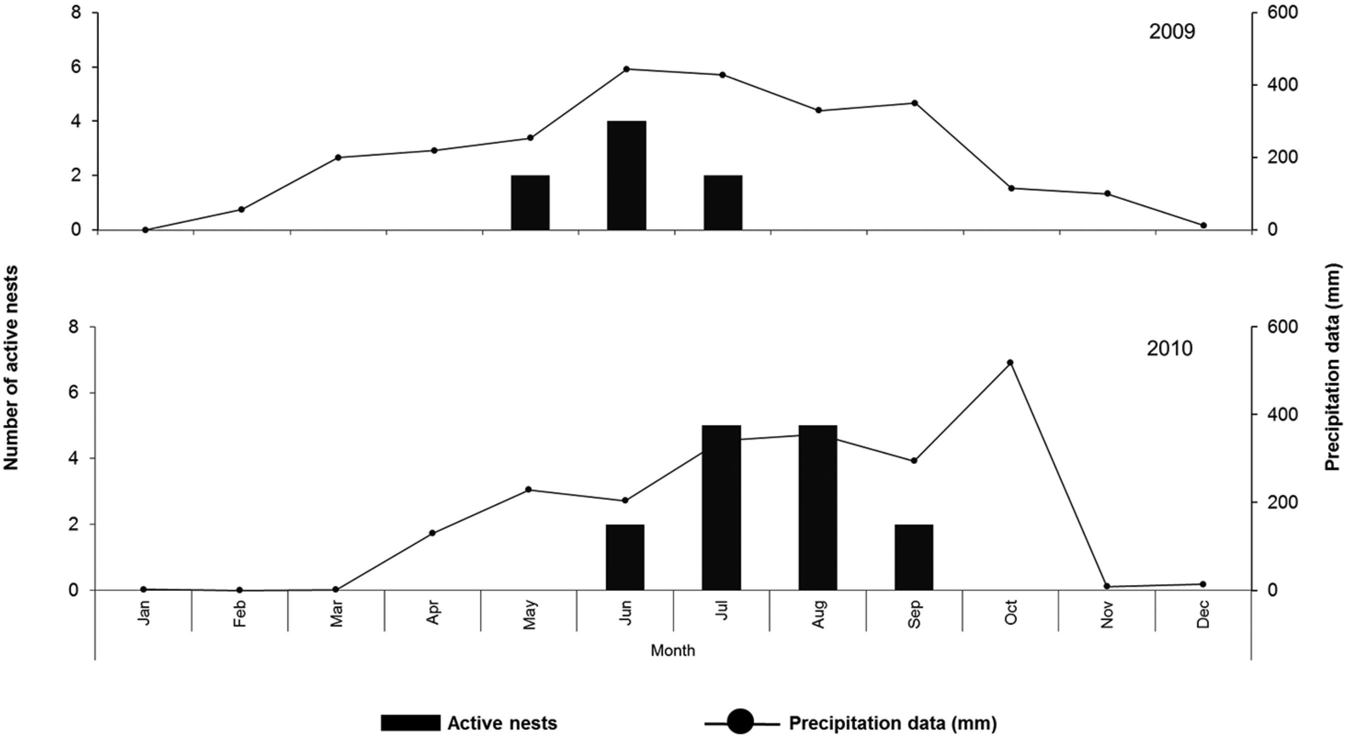

Fig. 1. Precipitation during 2009 and 2010 and the nesting period for the same two years of green-legged partridge at Khao Yai National Park.

1997; Sukumal et al., 2010), and then the number of woody stems were counted and the percentage cover estimated to the nearest 5% in each of the four height classes counted. Finally, the woody climber stems were counted.

We used the non-parametric Mann-Whitney U-test for comparisons of habitat variables between nests and random sites because our data were not normally distributed. We used logistic regression to model the data, where the probability of the plot being a nest was the response variable (nest = 1, random = 0). All variables were standardised for comparison on the same scale before input into the habitat models. The continuous variables (DBH, slope in degrees, number of stems per height class; Stem0.5–1, Stem1–3, Stem3–5, and Stem>5) were standardised by dividing the value by twice the standard deviation (Gelman, 2008). The percentage cover of plants in different height classes; Cover0.5–1, Cover1–3, Cover3–5, and Cover>5 were standardised by dividing the value by one hundred, and then transforming it by using an arcsine function (Sokal & Rohlf, 1995). Correlations between variables were tested using Spearman's rank correlations. Before entering the variables in a given model we tested which variables were highly correlated ($r > 0.5$). We found that there was a positive correlation between Stem0.5–1 and Cover0.5–1 ($r = 0.72$, $P < 0.0001$), Stem1–3 and Cover1–3 ($r = 0.68$, $P < 0.0001$), Stem3–5 and Cover3–5 ($r = 0.63$, $P < 0.0001$). These variables were not included in the same model. We used Akaike's Information Criterion adjusted for small sample size (AICc) to rank models based on their ability to explain the data and we used Akaike's weights (w_i) to estimate the relative likelihood of each model given the data (Akaike, 1973).

We followed the procedures of Suwanrat et al., (2014) to evaluate the model classification accuracy using the area under the receiver operating characteristic curve, AUC (Hosmer & Lemeshow, 2000). We chose an optimal threshold cut-off value for classification based on the AUC using the minimised difference between the proportions of nests correctly predicted (sensitivity) and the proportion of non-nests correctly predicted (specificity) (Fielding & Bell, 1997). We estimated the coefficients of parameters using model averaging when no one model had strong support (ΔAICc < 2; Richards et al., 2010). We used 85% confidence intervals to identify variables with significant influence on nest site selection; this interval renders model selection and parameter-evaluation criteria that are more congruent with the AIC results compared to a 95% CI (Arnold, 2010). Statistical analyses were performed using R Program 3.0.1 software (R Core Team, 2013), with the MASS (Venables & Ripley, 2002), AICcmodavg (Mazerolle, 2012) and PresenceAbsence packages (Freeman & Moisen, 2008).

RESULTS

We captured and colour marked 12 birds (3 males, 6 females and 3 unknown) during 2008–2010, of which nine birds from seven territories were fitted with a radio transmitter. We found 18 nests in total, of which 10 were found by following radio-tagged birds and the remainder by systematic searches.

Breeding period. The earliest first egg date of green-legged partridge was 12 May and the latest hatching date was 5 September. Initiation of egg-laying varied by about six weeks between years 2009 and 2010. Breeding in 2009 was first detected on 12 May and ended on 23 July (c. 9 wks.) when the last active nest was predated. In 2010, breeding was

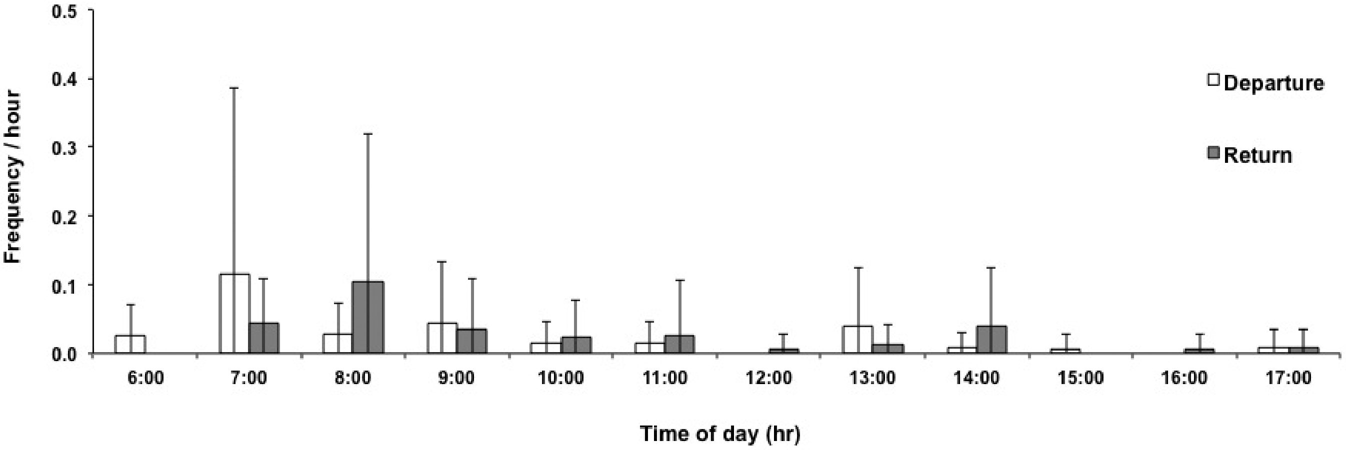

Fig. 2. Hourly variations (mean ± SD) in departure and return times of incubating female green-legged partridge ($N = 6$) at the Mo Singto Plot, Khao Yai National Park during 2009 and 2010.

first detected on 23 June and ended on 5 September (c. 11 wks.) when the last monitored nest hatched. Comparatively, rainfall started in mid-February in 2009 and in mid-April in 2010 (Fig. 1).

Incubation and clutch size. Two nests were video-monitored prior to clutch completion from which we were able to determine that green-legged partridge laid one egg every other day and that incubation began on the day the final egg was laid. The average incubation period was 19.25 ± 0.48 SE days (range = 19–21 days, N = four nests). Of the 16 nests used to calculate clutch size, the partridges laid clutches of two (N = one nest), three ($N = 10$ nests) or four (N = five nests) eggs. Mean clutch size was 3.19 ± 0.14 SE eggs ($N = 16$ nests). However, clutch size appeared to differ between the two years with an average of 4.0 eggs (N = four nests) in 2009 and an average of 2.9 eggs ($N = 10$ nests) in 2010 ($W = 40$, $P < 0.05$). Although the sample size for 2009 was small (four nests) only one of the 10 nests in 2010 contained two eggs. Hatching success was 95.8% ($N = 23$ eggs from seven nests). Three females re-nested after an earlier nest failure and on one occasion a female had a third attempt after successive failures. Second or third clutches were laid a mean of 17.60 ± 2.68 SE days after a failure (range = 11–27, N = five nests).

Incubation behaviour. We videotaped 2,286 hours of green-legged partridge at active nests; 942 hours in 2009 (N = four nests) and 1,344 hours in 2010 (N = four nests). Females spent 2,237.4 hours (median = 377.9) (97.9%) incubating and 48.6 hours (median = 2.1) (2.1%) in recess (with one individual comprising 30.5 hours of the total recess time). Timing of recesses appeared to decline through the day with females leaving the nest between 06:36–17:19 and returning 07:23–17:47. On one occasion, for no apparent reason, the female left the nest at night (22:53) and returned the following morning (06:27). Approximately 75% of the recesses occurred before noon (Fig. 2). The amount of time that females incubated continuously without taking a recess ranged from 4–13 days. The average time spent away from the nest per recess was 65 ± 10 SE minutes. The maximum time spent away from the nest during a single daytime recess was 186 minutes.

Nesting success. Of the 16 nests used for analysis of nest success, six were successful and 10 failed, giving an apparent nest success of 37.5%. Daily survival rate estimates were 0.94 ± 0.02 SE (95% CI = 0.89–0.97) giving an overall nest survival estimate of 26.8 ± 11.2 SE%. Six failed nests were depredated during the day, five by Northern pig-tailed macaques (*Macaca leonina*) and one by a Northern treeshrew (*Tupaia* cf. *belangeri*). A further four nests without cameras were depredated by unknown predators at unknown times. Macaques depredated eggs whether the female was present or not, whereas the treeshrew took eggs while the female was off the nest. From our video camera, it is evident that when a macaque finds a nest the females do not flush until the predator is within 1 m of the nest and sometimes not until touched by the macaque. Nest defense by female partridges, by actively pecking and spreading their wings in front of the predator was successful against rats *(Maxomys* cf. *surifer)* ($N = 39$ observations from two nests), Northern treeshrew (N = four observations from four nests), and Indochinese ground squirrel (*Menetes berdmorei)* (N = one observation).

Nest locations within home ranges. Thirteen nests within seven breeding territories were used for analysis (one nest in 2008, two nests in 2009 and 10 nests in 2010). Mean distance was not significantly different between nest to centre of home range (54.7 ± 9.1 SE m, $N = 13$) and nest to home range boundary (73.6 ± 6.5 SE m, $N = 13$; two sample *t*-test, $t = -1.6727$, $P = 0.055$), although suggestive that nests were closer to the centre.

Nest site selection. All nests were placed on the ground between the buttresses of a large tree (DBH range from 27.1–109.9 cm) in a shallow bowl lined with dead leaves and feathers (Fig. 3). The slope at nest sites ranged from 7° to 26°, and all nests were on the side of the tree facing downhill away from the nest tree (Table 1).

The microhabitat at nest sites had a higher percent cover of trees 3–5 m in height (Cover3–5) ($P < 0.05$) and a higher number of woody climber stems (Climber) ($P < 0.05$) than random sites. A set of eight regression models were generated to explain the probability of presence of a green-legged partridge nest and the null model was excluded from the

Table 1. Comparison of habitat variables between green-legged partridge nests (N = 17 nest locations) and random sites (N = 34 random locations).

Habitat Variables	Nest Sites			Random Sites			Mann-Whitney *U*-test
	Mean	**±**	**SE**	**Mean**	**±**	**SE**	**P-value**
Slope (degrees)	18.5	±	1.2	19.3	±	1.3	0.6377
Slope direction	147.5	±	8.1	142.4	±	9.6	0.7039
Tree density (stems) per height class:							
0.5–1m(Stem0.5–1)	60.6	±	3.4	66.7	±	3.4	0.3476
1–3m (Stem1–3)	49.9	±	3.3	55.3	±	3.7	0.6242
3–5m (Stem3–5)	14.2	±	1.8	9.8	±	1.7	0.0429
>5m (Stem>5)	18.3	±	1.5	13.7	±	1.6	0.0166
Tree coverage (%) per height class:							
0.5–1m (Cover0.5–1)	31.8	±	3.1	34.3	±	2.8	0.5649
1–3m (Cover1–3)	40.3	±	1.9	46.5	±	2.6	0.2046
3–5m (Cover3–5)	39.4	±	1.6	32.5	±	1.9	0.0283
>5m (Cover>5)	74.7	±	1.7	67.5	±	1.7	0.1525
DBH of nest trees: DBH	51.2	±	3.3	43.0	±	2.3	0.3902
Number of woody climbers(stems): Climber	5.2	±	2.9	1.6	±	2.2	0.0103

Table 2. Binary logistic regression models explaining probability of presence of green-legged partridge's nest in Khao Yai National Park, Thailand, based on variables included in models. Eight models were tested. Cover1–3, Cover3–5, and Cover>5 refer to tree coverage at these respective heights (m). Climber is number of woody climbers, Stem>5 is tree density at height >5 m.

Model	**LL**	**K**	**ΔAICc**	**w_i**	**AUC**
(8 models tested)					
Climber + Stem3–5 + Stem>5	−24.60	4	0.00	0.29	83.56
Climber + Stem>5+ Cover3–5	−25.02	4	0.84	0.19	81.49
Climber + Stem3–5	−26.22	3	0.87	0.19	77.08
Climber + Stem>5	−26.26	3	0.95	0.18	78.82
Climber + Cover3–5	−27.34	3	3.11	0.06	72.23
Stem3–5 + Stem>5	−27.60	3	3.64	0.05	77.51

LL is log-likelihood; K is number of parameters in the model; ΔAICc is difference in AICc (model score) value, model with ΔAICc value 0 has the most support, values between 0 and 2 have substantial support, values greater than 2 have less support; w_i= Akaike model weights; AUC = performance of the model which is calculated from the area under the curve.

Fig. 3. Location of a green-legged partridge nest between the buttress of a large tree. The arrow shows the location of nest.

table because of a lack of support relative to the tested top total models (Table 2). A candidate set of eight regression models was fitted to explain nest site selection of green-legged partridge. The best model, based on ΔAICc and AICc weight (Table 2), included number of woody climbers, tree density at height 3–5 m and tree density at height >5 m which correctly predicted nest site selection in 83.6% of cases. Model averaging was estimated for the coefficients (Table 2) based on the accumulated 95% model weight. Estimated coefficients for number of woody climbers (Climber), tree density at height 3–5 m (Stem3–5), tree density at height >5 m (Stem>5), and tree coverage at height 3–5 m (Cover3–5) had a significantly positive influence on nest site selection of green-legged partridge (Table 3). In general, there was not a clear trend for habitat selection in terms of vegetation coverage surrounding the nest perhaps due to the overall small sample size or perhaps due to overall homogeneity of the vegetation and habitat.

Table 3. Estimates of coefficients derived from model averaging (averaged across all models that contain such variables) and unconditional SE and its 85% confidence interval.

Variables	Estimated Coefficient	Uncond. SE	Lower 85%	Upper 85%
Climber	1.84	0.95	0.47	3.21
Stem3–5	1.40	0.77	0.30	2.51
Stem>5	1.38	0.70	0.37	2.38
Cover3–5	4.71[a]	3.09	0.27	9.16

Estimated coefficients of variables that suggest significant effects on nest site selection of green-legged partridge. Overlap with zero indicates a weak effect or no effect.

[a] Coverage was arcsine transformed while other variables were standardised.

DISCUSSION

Breeding period and clutch size. The breeding period of the green-legged partridge occurred from May through September, which coincided with peak annual rainfall (Fig. 1), which is also the peak of arthropod abundance at this site (Steward et al., 2013). This pattern of greater abundance and biomass of invertebrates during the wet season is widespread in the tropics especially for litter insects (Lowman, 1982; Nummellin, 1989; Anu et al., 2009). That the green-legged partridge nesting period is influenced by rainfall (and hence food availability) is consistent with our finding that they bred earlier in 2009 when the rainy season started earlier (Fig. 1). Such patterns have been recorded elsewhere (e.g., Murton & Westwood, 1977; Moreau, 1950; McAuley & Longcore, 1989; Stutchbury & Morton, 2001). Higher food availability has also been demonstrated to lead to larger clutch sizes (Rotenburry & Wiens, 1989; Clifford & Anderson, 2001; Spottiswoode, 2009) and this may account for the higher average clutch size observed for green-legged partridge in 2009 although caution is required as our sample sizes are relatively small and only based on two seasons. The nesting season of the green-legged partridge appeared to begin at least four weeks later than other Galliformes at the study site, including Siamese fireback (*Lophura diardi*) and silver pheasant (*L. nycthemera*), which nested during April to June (Sukumal et al., 2010).

Nesting behaviour and incubation. Green-legged partridge had extremely high nest attentiveness (97.9%) and an incubation behaviour similar to that of other Galliformes with female-only incubation and precocial young (Deeming, 2002). Similar attendance incubation rates were also reported for the greater sage-grouse (96%) (*Centrocercus urophasianus*) in Nevada, USA (Coates & Delehanty, 2008) and in other Galliformes (Johngard, 1973). In our study, for eggs that were not depredated, there was a high hatching success rate (95.8%, while only one egg was observed as unhatched), suggesting that the green-legged partridge rates are typical as the overall average for birds species has been reported at approximately 90% (Koenig, 1982).

All documented predation events occurred during daylight and were caused by mammalian predators. This suggests that these predators detected the nest by visual rather than olfactory cues. Similar results have been reported previously for ground and above ground nesting birds at the same study site (74% of predation events took place during the day) (Pierce & Pobprasert, 2013). Data from the video cameras showed that predation by macaques was independent of the presence or absence of the female on the nest as the macaque chased her away from the nest. However, predation from other potential predators (i.e., rats, treeshrews and squirrels) was only successful during the absence of the brooding female. Sitting on the nest for most of the incubation period could be seen as an anti-predator strategy.

Nesting success and nest site selection. No information is available for other *Tropicoperdix* as well as *Arborophila*, to compare with in the tropics. However, when compared to other galliformes in the same study site, our apparent nest success (38%) was similar to the estimated nest success of Siamese fireback (45%, Sukumal et al., 2010). Our estimate of 26% nest success based on daily survival rate using the package RMark, was higher than that reported for the Siamese fireback in another study site in Thailand (8%; Suwanrat et al., 2014) where extremely low nesting success was reported for firebacks and several other species possibly due to the small and fragmented status of that site (Gale et al., unpubl. data.).

The selection of buttresses for nesting by the green-legged partridge is similar to that reported for Siamese fireback (Sukumal et al., 2010) in MST and other study areas (Suwanrat et al., 2014), and also reported for other Galliformes species living in different habitats such as the Tibetan Eared-pheasant (*Crossoptilon harmani*) in Lhasa, Tibet (Lu & Zheng, 2003), and Chinese grouse (*Bonasa sewerzowi*) in Lianhuashan, Northern China (Sun et al., 2007). In all cases the selection of buttress, or buttress type structures, was hypothesized to be a consequence of females trying to limit detection by predators.

With regard to the main factors resulting in nest mortality and predation, selection of a nest site that reduces detection by predators and is protected from harsh weather should be preferred. The nesting habitat models suggested that percent coverage of trees 3–5 m in height (Cover3–5) and numbers of woody climber stems were found to be greater at green-legged partridge nest sites than at random sites. However, there was no clear trend statistically in terms of percent cover for nest site selection, this may be an effect of small sample size. In broad terms, although not statistically significant, stems and cover below three meters were lower at nests compared to random sites while cover and stem density was higher above three meters at nests compared to random sites. Small trees with heights of 0.5–1 m (Stem0.5–1) and 1–3 m (Stem1–3) did not significantly influence the nest site selection model as it did for Siamese fireback in the region (Suwanrat et al., 2014). The microhabitat selection with a relatively high percentage cover of large trees may hide the nest more from arboreal and less from ground predators. It is also possible that the partridge prefers slightly more open understory to be able to detect approaching predators (Lima, 1993). In this study, pig-tailed macaque was the main predator. The macaques near our study site have been shown to have multi-level searching patterns and travel in troops, so their behaviour gives them access to food from every forest strata (Albert et al., 2013). They have been reported to depredate most of the understory nesting bird species in the area (Pierce & Pobprasert, 2013). Therefore, a lower short tree density (trees lower than 5 m) may be advantageous to females for detecting approaching predators. Several studies of ground nesters, e.g., Northern bobwhite (*Colinus virginianus*; Taylor et al., 1999), grey partridge (*Perdix perdix*; Rands, 1988), sage grouse (*Centrocercus urophasianus*; Gregg et al., 1994) and lesser prairie chicken (*Tympanuchus pallidicinctus*; Rilay et al., 1992) have shown that the microhabitat at the nest site contains denser vegetation compared to random sites and that vegetation can influence nesting success by limiting detectability from approaching or searching predators. The nest site selection of green-legged partridge may also follow this strategy; however, nest site selection may be a complex trade-off between reducing the chance of detection by predators and escaping if they are detected (Weidinger, 2002).

The mean distance from a nest to centre of a home range appeared to be shorter than from nest to edge of home range, although the difference was not significant (P = 0.055), suggesting that females might select sites in the more familiar part of the home range (core area). Only males were observed to defend the territory with dawn calling while the female was incubating (Ong-in, unpubl. data). Although little information is available, our results contrast with other Galliformes, which mostly nested at the edge of their home range. For example, Sun et al., (2007) found that female Chinese grouse nested near the edge of their home range and that most activities (i.e., foraging and roosting) occurred away from their nest presumably to decrease the risk of nest predation.

In conclusion, here we report details on the nesting ecology and nest site selection of a relatively common but ecologically unknown *Tropicoperdix* partridge. In light of the proposed taxonomic reclassification, green-legged partridge can be considered distantly related to *Arborophila* (hill- partridges) within a separate clade (Chen et al., 2015). Moreover, Chen et al., (2015) also showed that the two genera have subtle morphological differences, suggesting perhaps they have ecological and/or behavioural differences. The two genera are commonly sympatric in Southeast Asian forests (Madge & McGowan, 2002) using similar microhabitats. From this we might predict convergence in their ecology, including nesting behaviour and nest site selection, for which the data presented here, could provide initial baseline comparisons. Unfortunately no data on similar ecological aspects are currently available for other species within the genera *Tropicoperdix* and *Arborophila*. We therefore stress the importance of collecting similar data on other *T. chloropus* populations, as the results presented here, are for a single population of this species inhabiting a large geographical range, as well as for other *Tropicoperdix* and *Arborophila* species, in order to investigate potential ecological differences between these genera.

ACKNOWLEDGEMENTS

We wish to thank the Department of National Parks, Wildlife and Plant Conservation and Khao Yai National Park for allowing us to conduct research in the park. We thank Philip D. Round and H. Lloyd for their valuable comments on this paper. We thank Warren Y. Brockelman and A. Nathalang for providing the Mo Singto Plot database and annual rainfall database. We also thank the following people for their help with fieldwork: U. Matmoon, M. Klinklai, W. Sankamethawee, J. Khoonwongsa and K. Pobprasert. We thank N. Sukumal, M. Plio-sungnoen and S. Suwanrat for help with data analysis. This research was supported by the TRF/BIOTEC Special Program for Biodiversity Research and Training grant (BRT T_353005, R_349004, R_346004). The National Research Council of Thailand (NRCT), and The Pheasant Conservation Project, King Mongkut's University of Technology Thonburi (Thailand) Research Grant Support and Development

LITERATURE CITED

Akaike H (1973) Information theory and extension of the maximum likelihood principle. In: Petrovand BN & Csàki F (ed.) Second International Symposium on Information Theory. AkademiaiKiàdo, Budapest, Hungary. Pp. 267–281.

Albert A, Savini T & Huynen M-C (2013) The role of *Macaca* spp. (Primates: *Cercopithecidae*) in seed dispersal networks. Raffles Bulletin of Zoology, 61: 423–434.

Anu A, Sabu TK & Vineesh PJ (2009) Seasonality of litter insects and relationship with rainfall in a wet evergreen forest in south Western Ghats. Journal of Insect Science, 9: 1–10.

Arnold TW (2010) Uninformative parameters and model selection using Akaike's information criterion. Journal of Wildlife Management, 74: 1175–1178.

BirdLife International (2013) Species factsheet: *Arborophila chloropus*. http://www.birdlife.org. (Accessed 11 November 2013).

Brockelman WY, Nathalang A & Gale GA (2011) The Mo Singto Forest Dynamics Plot, Khao Yai National Park, Thailand. Natural History Bulletin of the Siam Society, 57: 35–56.

Chen D, Liu Y, Davison GWH, Dong L, Chang J, Gao S, Li S-H & Zhang Z (2015) Revival of the genus *Tropicoperdix* Blyth 1859 (Phasianidae, Aves) using multilocus sequence data. Zoological Journal of the Linnean Society, 175: 429–438.

Clifford LD & Anderson DJ (2001) Food limitation explains most clutch size variation in the Nazca booby. Journal of Animal Ecology, 70: 539–545.

Coates PS & Delehanty DJ (2008) Effects of environmental factors on incubation patterns of Greater Sage-Grouse. Condor, 110: 627–638.

Dai B, Dowell SD, Garson PJ & He FQ (2009) Habitat utilization by the threatened Sichuan partridge *Arborophila rufipectus*: Consequences for managing newly protected areas in southern China. Bird Conservation International, 19: 187–198.

Dai B, Dowell SD, Martin RP & Williams RSR (1998) Conservation status of the Sichuan hill-partridge *Arborophila rufipectus* in China. Bird Conservation International, 9: 349–359.

Deeming DC (2002) Behavior patterns during incubation. In: Deeming DC (ed.) Avian Incubation: Behavior, Environmental, and Evolution. Oxford University Press, New York. Pp. 63–87.

del Hoyo J, Collar NJ, Christie D, Elliot A & Fishpool LDC (2014) Illustrated Checklist of the Birds of the World (Vol.1) Lynx Edicions.

Environmental System Research Institute (2009) ArcGIS: Release 9.3.1. http://www.esri.com. (Accessed 15 August 2013).

Fielding AH & Bell JF (1997) A review of method for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation, 24: 38–49.

Freeman EA & Moisen G (2008) PresenceAbsence: an R package for presence-absence model analysis. Journal of Statistical Software, 23: 1–31.

Fuller RA, Carroll JP & McGowan PJK (2002) Status survey and conservation action plan 2000–2004: Partridges, Quails, Francolins, Snowcocks, Guineafowl and Turkeys. IUCN, Gland, Switzerland and Cambridge, UK, 60 pp.

Gelman A (2008) Scaling regression input by dividing by 2 standard deviations. Statistics in Medicine, 27: 2865–2873.

Gregg MA, Crowford JA, Drut MS & DeLong AK (1994) Vegetation cover and predation of sage grouse nests in Oregon. Journal of Wildlife Management, 58: 162–166.

Hill DA & Robertson PA (1988) The Pheasant: Ecology, Management and Conservation. Blackwell Scientific Publications, Oxford.

Hosmer DW & Lemeshow S (2000) Applied Logistic Regression. Wiley, NY.

IUCN (2014) The IUCN Red List of Threatened Species, Gland, Switzerland. http://www.redlist.org. (Accessed 11 December 2014).

Johngard PA (1973) Grouse and Quail in North America. University of Nebraska Press, Lincoln, Nebraska.

Jones J (2001) Habitat selection study in avian ecology: A critical review. The Auk, 118: 557–562.

Keane A, Brooke ML & McGowan PJK (2005) Correlates of extinction risk and hunting pressure in gamebirds (Galliformes). Bird Conservation International, 18: 260–266.

Kitamura S, Yumoto T, Poonsawad P, Noma N, Chuailua P, Plongmai K, Maruhashi T & Suckasaem C (2004) Pattern and impact of hornbill seed dispersal at nest trees in a moist evergreen forest in Thailand. Journal of Tropical Ecology, 20: 545–553.

Klett AT, Duebbert HF, Faanes CA & Higgins KF (1986) Techniques for studying nest success of ducks in upland habitats in the Prairie Pothole Region. U.S. Fish and Wildlife Service, Resource Publication 158. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/birds/nest/ index.htm (Version 16JUL97) (Accessed 17 September 2014).

Koenig WD (1982) Ecological and social factors affecting hatchability of eggs. The Auk, 99: 526–536.

Laake J & Rexstad E (2008) RMark-an alternative to building linear models in MARK. In: Cooch E & White G (eds.) Program MARK: a Gentle Introduction. 9th Edition. Colorado State University. Pp. 1–115.

Lekagul B & Round PD (1991) A Guide to the Birds of Thailand. Saha Karn Bhaet Group, Bangkok.

Lima SL (1993) Ecological and evolutionary perspectives on escape from predatory attack: A survey of North American birds. The Wilson Bulletin, 105(1): 1–47.

Lowman MD (1982) Seasonal variation in insect abundance among three Australian rainforests, with particular reference to phytophagus types. Australian Journal of Ecology, 7: 353–361.

Lu X & Zheng G-M (2003) Reproductive ecology of Tibetan eared pheasant *Crossoptilon harmoni* in scrub environment, with special reference to the effect of food. Ibis, 145: 657–666.

Madge S & McGowan PJK (2002) Pheasants, Partridges and Grouse: A Guide to the Pheasants, Partridge, Quails, Grouse, Guineafowl, Buttonquails and Sandgrouse of the world. Christopher Helm, London.

Martin TE (1995) Avian life history evolution in relation to nest sites, nest predation, and food. Ecological Monographs, 65: 101–127.

Martin TE, Paine C, Conway CJ, Hochachka WM, Allen P & Jenkins W (1997) BBIRD Field Protocal: Breeding Biology Research and Monitoring Database. Biological Resources Division, Montana Cooperative Wildlife Research Unit, Missoula.

Mazerolle MJ (2012) AICcmodavg: model selection and multimodel inference based on (Q)AIC(c). R package version 1.26. http://CRAN.Rproject.org/package=AICcmodavg. (Accessed 10 July 2013).

McAuley DG & Longcore JR (1989) Nesting phenology and success of ring-necked ducks in East-central Maine. Journal of Field Ornithology, 60: 112–119.

Mohr CO (1947) Table for equivalent populations of North American Mammals. American Midland Naturalist, 37: 223–249.

Moreau RE (1950) The breeding season of African bird: 1. Land birds. Ibis, 92: 223–267.

Murton RK & Westwood NJ (1977) Avian breeding cycles. Oxford Clarendon Press.

Nummellin M (1989) Seasonality and effect of forestry practices on forest floor arthropods in the Kibale Forest, Uganda. Fauna Norvegica (Series B), 36: 17–35.

Pierce AJ & Pobprasert K (2007) A portable system for continuous monitoring of bird nests using digital video recorders. Journal of Field Ornithology, 78: 322–328.

Pierce AJ & Pobprasert K (2013) Nest predators of Southeast Asian evergreen forest birds identified through continuous video recording. Ibis, 155: 419–423.

Rands MRW (1988) Effect on nest site selection on nest predation in grey partridge.Ornis Scandinavica, 19: 35–40.

R Development Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org. (Accessed 1 June 2013).

Richards SA, Whittingham MJ & Stephens PA (2010) Model selection and model averaging in behavioral ecology: the utility of the IT-AIC framework. Behavior Ecology Sociobiology, 65: 77–89.

Riley TZ, Davis CA, Ortiz M & Wisdom MJ (1992) Vegetative characteristics of successful and unsuccessful nests of lesser prairie chickens. Journal of Wildlife Management, 52: 382–387.

Robson C (2008) A Field Guide to the Birds of Thailand and South-East Asia. Asia Books, Bangkok.

Rotenburry JT & Wiens JA (1989) Reproductive biology of shrubsteppe passerine birds: Geographical and temporal variation in clutch size, brood size, and fledging success. The Condor, 91: 1–14.

Round PD, Pierce AJ, Sankamethawee W & Gale GA (2011) The avifauna of the Mo Singto Forest Dynamics Plot, Khao Yai National Park, Thailand. Natural History Bulletin of Siam Society, 57: 57–80.

Savini T, Bosch C & Reichard UH (2008) Home-range characteristics and the influence of seasonality on female reproduction in white-handed gibbons *(Hylobates lar)* at Khao Yai National Park, Thailand. American Journal of Physical Anthropology, 135: 1–12.

Sokal RR & Rohlf FJ (1995) Biometry, 3rd Edition. W. H. Freeman and Company, New York.

Spottiswoode CN (2009) Fine-scale life-history variation in sociable weavers in relation to colony size. Jounal of Animal Ecology, 78: 504–512.

Steward JS, Round PD & Milne JR (2013) Food availability fails to explain asynchronous breeding of two syntopic oriental trogons. The Condor, 115: 838–846.

Stutchbury, Bridget J & Morton ES (2001) Behavioral ecology of tropical birds. Academic Press.

Sukumal N, Gale G & Savini T (2010) Sub-montane habitat selection by a lowland pheasant. Raffles Bulletin of Zoology, 58: 391–401.

Sun Y-H, Fang Y, Jia C-X, Klaus S, Swenson JE & Scherzinger W (2007) Nest site selection of Chinese grouse *Bonasa sewerzowi* at Lianhuashan, Gansu, China. Wildlife Biology, 13: 68–72.

Suwanrat J, Ngoprasert D, Sukumal N, Suwanwaree P & Savini T (2014) Reproductive ecology and nest-site selection of Siamese fireback in lowland forest. Raffles Bulletin of Zoology, 62: 581–590.

Taylor SJ, Church KE & Rusch DH (1999) Microhabitat selection by nesting and brood rearing of northern bobwhite in Kansan. Journal of Wildlife Management, 63: 389–394.

Venables WN & Ripley BD (2002) Modern Applied Statistics with S. 4th Edition. Springer, New York.

Weidinger K (2002) Interactive effects of concealment, parental behaviour and predators on the survival of open passerine nests. Journal of Animal Behaviour, 71: 424–437.

White GC & Burnham KP (1999) Program Mark: survival estimation from population of marked animals. Bird study, Supplement, 46: 120–138.