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Research Article

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Abstract

The Giant Nuthatch *Sitta magna* is restricted to southwestern China, eastern Myanmar, and northern Thailand. Although globally endangered, most aspects of its ecology remain as yet unquantified. To assess its habitat associations and population size, we conducted point counts with playback at 42 sample points across 12 discrete historical and potential localities within its Thai range during October to November 2015. Eleven habitat variables were measured, including three site-level vegetation variables and eight landscape variables were assessed, using geographic information system land cover maps. N-mixture models were applied to estimate density and extrapolate the size of the population. The Giant Nuthatch was found at four localities (12 of the 42 sample points) at elevations between 1,192 m and 1,738 m. It was not detected at four historical Giant Nuthatch localities in protected areas. Abundance increased with increasing elevation, increasing proportion of evergreen forest, and greater distance from villages. We estimated that the Thai population of Giant Nuthatch was approximately 964 individuals based on an average density of 1.96 individuals/km^2 in approximately 491.8 km^2 of appropriate forest habitat at 1,192 m to 1,951 m elevation. This may be an overestimate because available forest cover maps and images do not distinguish between the characteristic, patchily distributed, lower montane open pine–oak forest association used by Giant Nuthatch and denser, closed-canopy forest. Although Thailand's Giant Nuthatch population may be better protected than those in adjoining countries, we suggest that it remains threatened by forest fragmentation and habitat degradation throughout its range. Further comprehensive research is needed to assess the status of the remaining global population and the reasons for its scarcity.

Keywords

population estimate, distribution, N-mixture models, habitat degradation, *Sitta magna*

Introduction

The Giant Nuthatch (Aves: Sittidae: *Sitta magna*) is a resident species of mixed coniferous and broad-leaved forest, in which pines (*Pinus* spp.), oaks, and chestnuts (Fagaceae) predominate at montane elevations between approximately 1,200 and 3,400 m (BirdLife International, 2016; Round, 1983). Its world range encompasses southwestern China, eastern Myanmar, and northern Thailand (BirdLife International, 2016; Harrap & Quinn, 1996; Matthysen, 1998). The global threat status of Giant Nuthatch was uplisted from vulnerable to endangered in 2012 (BirdLife International, 2016) due primarily to the loss and degradation of pine and mixed forest habitats through shifting cultivation, logging, and frequent fires. The nuthatch has disappeared from some former localities and has become rarer in all countries in its range (Bezuijen, Eaton, Gidean, & Rheindt, 2010; BirdLife International, 2016; Round, 1984). Its global population is thought to have declined dramatically and was estimated at approximately 1,000 to 2,499 individuals with

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only 6 to 50 mature individuals in the largest subpopulation (BirdLife International, 2016). There is great uncertainty as to its numeric status, however. The population for Yunnan province, China, alone was estimated at 800 to 2,000 mature individuals (BirdLife International, 2016), but this was based on very limited data. There are no recent published records whatsoever from Myanmar. However, even an upper limit of 2,499 individuals across its world range would be indicative of extreme scarcity for this relatively small bird. Clearly, there is an urgent need for more information on the status of this species.

Montane areas in northern Thailand have been subjected to rapid land-use change, especially since the 1960s (Fox, Krummel, Yarnasarn, Ekasingh, & Podger, 1995). Overall, forest cover in Thailand was reduced from 53% of the country's area in 1961 to approximately 25% in 1998, an average annual loss of 120,000 ha (Charuphat, 2000; Fox & Vogler, 2005). Moreover, road development and human population growth expanded greatly during the same period. During 1976 to 1989, approximately 1.2 million new agricultural households and 17,000 km of roads were added in northern and northeastern Thailand (Cropper, Griffiths, & Mani, 1999). Deforestation not only causes habitat loss but also increases habitat fragmentation, reducing patch sizes and core areas and isolating suitable habitats (MacDonald, 2003; Pattanavibool & Dearden, 2002). Activities such as slashing and burning of natural vegetation, associated with shifting cultivation, and excessive use of pesticides are also major factors decreasing the habitat quality (Fox & Vogler, 2005; Rerkasem, 1998).

Nonetheless, coverage of protected areas in the montane zone of three provinces of northern Thailand in which Giant Nuthatch occurs (Chiang Rai, Chiang Mai, and Mae Hong Son) is high: 55% of the montane forest area above 1,000 m (2,146 km^2) is already protected as either national park or wildlife sanctuary (data retrieved from Royal Forest Department [RFD] geographic information system shapefiles). Despite this relatively high level of protection, the Giant Nuthatch population in Thailand is still thought to be declining.

Our objective was to estimate the likely population size of Giant Nuthatch in Thailand to assess the country's contribution to the global population of the species and contribute toward the formulation of a species conservation plan.

We focused on the historical and potential areas of occurrence to assess the presence and estimate the abundance of the nuthatch throughout its range in Thailand. We expected that habitat features such as the proportion of pine and hill evergreen forest, canopy height, and tree density would all positively influence the probability of presence.

Methods

Study Area

Northern Thailand has a complex, mainly mountainous, terrain supporting a mosaic of different forest types (Smitinand, 1977) that rises to a maximum elevation of 2,565 m. The study was conducted at sites with historical records of Giant Nuthatch identified from BirdLife International (2001), Bird Conservation Society of Thailand (recent unpublished data), and other potential areas within the historical range of Giant Nuthatch. Surveys extended as far east as the western flank of the Khun Tan mountain range which delineates the eastern border of Chiang Mai Province and west to the border with Myanmar (18°20′–20°7′N, 97°40′–99°24′E; Table 1, Figure 1).

The surveys were restricted to forest areas between 1,000 and 1,830 m, as there were no confirmed historical records below 1,200 m, while there was only one record above 1,830 m (Deignan, 1946; Lekagul & Round, 1991; Robson, 2000). Sampling large areas of forest completely randomly was not logistically feasible due to the ruggedness of the terrain. We therefore selected 42 accessible survey points (Figure 1) where native pines *Pinus kesiya* Royle ex Gordon were frequent or occasionally dominant at elevations above 1,000 m, and each point was located at least 1 km apart to avoid site dependence. We conducted observations on three occasions at each point from October 6 to November 24, 2015.

Observation Methods

We conducted field studies during the prebreeding season when bird activity was thought to be high and individuals frequently responded to each other's calls (Charonthong & Sritasuwan, 2009). Because Giant Nuthatches have loud and distinctive calls, we considered that the probability of missing calling nuthatches that were present in the area of study was low. We conducted point-count surveys by using playback of vocalizations of Giant Nuthatch to increase the probability of detection (Bibby, Burgess, & Hill, 1992). Recordings of calls and songs were obtained from the Xeno-canto database (www.xeno-canto.org). During the surveys, the nuthatch contact call was played for 30 s, followed by 5 min of observation and repeated. If there was no response in either the first or the second round, a third round in which the bird's territorial song was played instead, for 30 s, followed by observations for a further 5 min, took place. Playback of song was then repeated once more if there was still no response. Each session might therefore extend to a maximum of 22 min (30 s of call or song +5 min observation, repeated four times).

Table 1. Localities Surveyed for Giant Nuthatch During This Study (2015) Including Known Historical Sites and Potential Sites, Protection Status of Each Locality, and Detection During This Study.

Survey localities	GPS locations	Designation	Latest historical record	Detection during this study
Doi Langka, Khun Chae National Park (Chiang Mai and Chiang Rai)	19°00′N, 99°05′E	Protected area	Riley (1938)	No
Huai Hin Lad Nai Village, Wiang Pa Pao District (Chiang Rai)	19°17′N, 99°20′E	Nonprotected	No records known	No
Mae Ngai Watershed Station (Chiang Mai)	19°30′N, 98°48′E	Nonprotected	2009 (sight record)[b]	Yes
Baan Mae Kiang, Mueang Na District (Chiang Mai)	19°42′N, 98°50′E	Nonprotected	2009 (sight record)[b]	No
Doi Ang Khang Royal Project Center (Chiang Mai)	19°51′N, 99°02′E	Nonprotected	1983 onward	Yes
Doi Pha Hom Pok National Park (Chiang Mai)	20°00′N, 99°09′E	Protected Area	1982 sight record (BirdLife International, 2001)	No
Doi Lang, Doi Pha Hom Pok National Park (Chiang Mai)	20°03′N, 99°05′E	Protected Area	2012 onward	Yes
Pang Ung Royal Project Center (Mae Hong Son)	19°29′N, 97°54′E	Nonprotected	No records known	No
Pha Son Wat Chan Royal Project Center (Chiang Mai)	19°05′N, 98°20′E	Nonprotected	No records known	No
Khun Mae Ya Watershed Management Unit (Mae Jok Luang), Huai Nam Dang National Park (Chiang Mai and Mae Hong Son)	19°14′N, 98°35′E	Nonprotected	1997 sight record (BirdLife International, 2001)	No
Doi Inthanon National Park (Chiang Mai)	18°30′N, 98°30′E	Protected area	1931 (two specimens)	No
Doi Chiang Dao Wildlife Sanctuary (Chiang Mai)	19°22′N, 98°50′E	Protected area	1987 onward	Yes
Doi Suthep-Pui National Park[a] (Chiang Mai)	19°00′N, 99°05′E	Protected area	1967 (a specimen)	

Note. Province name is in parentheses.
[a]Doi Suthep-Pui National Park (not surveyed) has had no records of Giant Nuthatch since 1967 despite multiple surveys over the past 50 years.
[b]Unattributed sight records are those held on file by Bird Conservation Society of Thailand.

We recorded the presence of the species by either sighting (measuring the distance of the bird from the observer with Bushnell Sport 450 laser range finder) or when hearing vocalization (the distance was estimated). Surveys were conducted from sunrise to 10:00 h, only on days without rain or high winds, by two observers.

Vegetation Sampling

We measured habitat characteristics at each sample point following Bibby et al. (1992) to assess possible habitat requirements of the species. We used a five-factor angle-gauge centered at the sample point (Avery & Burkhart, 2015), which is held a set distance (60 cm) from the eye of the observer. All trees that were larger than the width of the angle gauge, as viewed from the center of the plot, were counted. Three components: tree species, height, and diameter at breast height were recorded (Table 2), and diameter at breast height was used for calculating the basal area (m^2/ha).

We measured landscape composition metrics within a 300 m radius around each sample point (Table 2). This distance was based on very limited telemetry data indicating that a male Giant Nuthatch territory was approximately 19.7 ha (Techachoochert, 2018). Distance from the observation point to the nearest village was measured using ArcGIS 10.6 (ESRI, Redlands, USA).

The pine species with which Giant Nuthatches are associated in northern Thailand, *P. kesiya*, typically occurs mixed with broad-leaved trees. Pines do not usually dominate, except in small stands on drier ridges, so that areas of hill evergreen forest in which pines were frequent were usually indistinguishable from other hill evergreen forest associations in available satellite images

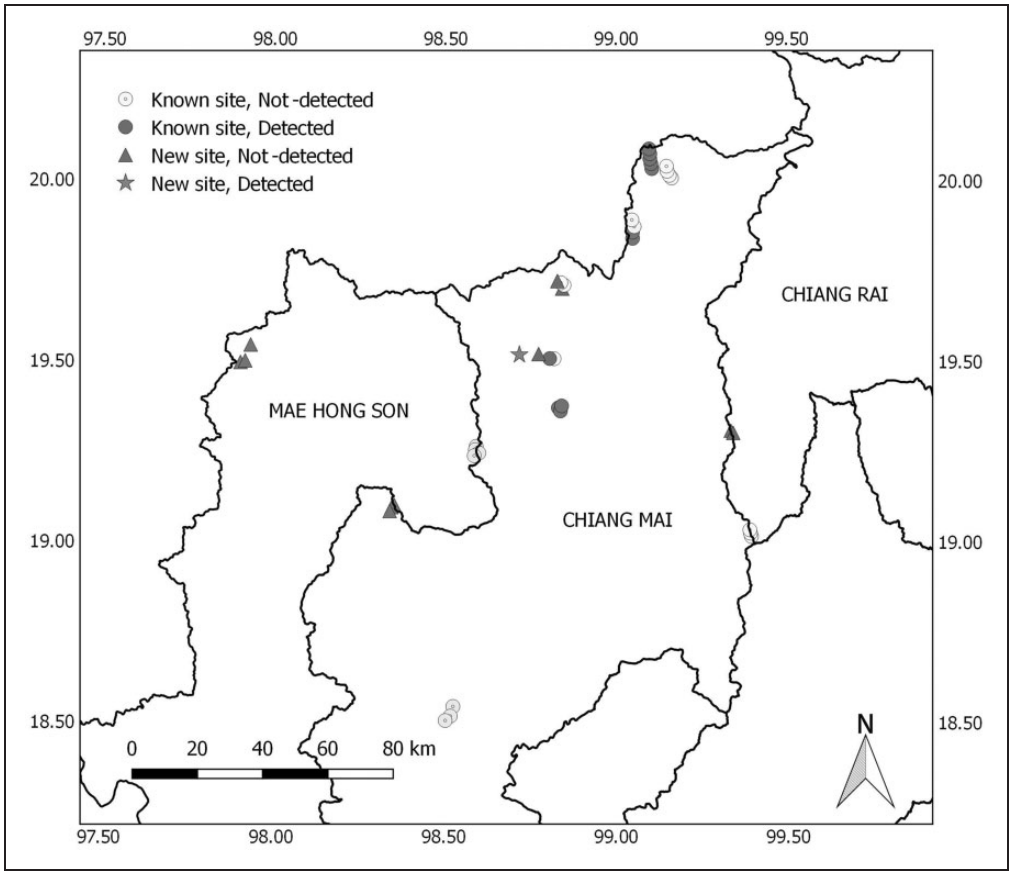

Figure 1. Map showing 42 survey points across 12 localities in northern Thailand. Former known localities but not detected (18 sites); former known localities where detected (11 sites). Additional sites with apparently suitable habitat (not detected, 12 sites; detected, one site).

Table 2. Descriptions, Means, and *SE* of Site and Landscape-Scale Variables in 42 Sample Sites Where Giant Nuthatch Was Detected or Nondetected, Used in Our N-Mixture Models Analysis.

		Detected		Nondetected	
Variable	Description	Mean	*SE*	Mean	*SE*
Site covariates					
BA	Basal area (m^2/ha) at sample point	16.6	1.6	21.8	1.9
Height	Average canopy height of counted trees	16.9	1.9	18.1	0.7
Oak	Oak ratio (number of oaks and chestnuts or total number of trees counted with angle gauge)	0.21	0.06	0.14	0.04
Landscape covariates					
Elev	Elevation (m) above sea level	1,536	41	1,346	39
Slope	Slope (%) from horizontal	12.5	0.8	14.6	1.4
Aspect	Aspect (degrees) from the north	157.5	29.3	169.3	19.1
Village	Distance (km) to the closest village	8.0	1.3	6.7	0.6
Pine	Proportion of pine forest in 300 m radius around survey point	0.230	0.121	0.450	0.087
Evg	Proportion of hill evergreen forest in 300 m radius around survey point	0.650	0.121	0.250	0.075
Mix	Proportion of mixed deciduous forest in 300 m radius around survey point	0	0	0.030	0.018
Agri	Proportion of agricultural land in 300 m radius around survey point	0	0	0.220	0.073

Note. *SE* = standard error.

of forest cover. We used accessible maps of forest cover provided by the Forest Survey and Assessment Division, RFD, Thailand based on Landsat data from year 2000 and intensive ground surveys. Forest cover was classified following Smitinand's (1977) forest classification which separates pine forest from hill evergreen forest. However, Maxwell (2004) and other authors (Santisuk, 1988; Werner & Santisuk, 1993) do not use the term "pine forest" but refer to this as either "primary evergreen forest with pines" or "lower montane pine–oak forest."

Following Smitinand (1977), pine forest was defined as forest about 200 to 1,300 m in elevation with poor acid soils in which either of the native pines *P. kesiya* or *P. merkusii* Jungh et De Vriese are predominant. Although pine forest classified by RFD therefore included some areas of *P. merkusii*—deciduous dipterocarp association that were not used by Giant Nuthatches, as most such areas were below 1,000 m they could be excluded from the areas covered by our assessment. Hill evergreen forest, also known as lower montane forest, was defined as forest at or above 1,000 m elevation with annual rainfall 1,500 to 2,000 mm. The dominant trees were oaks and chestnuts (Fam. Fagaceae), but pines also occur admixed in many areas.

Abundance Model Analysis

We assessed the abundance of Giant Nuthatches in our study area by using N-mixture models (Royle, 2004). We assumed population closure as our surveys took place over relatively few successive days at each survey point. N-mixture provides an estimate of two parameters: mean abundance per site (n) and detection probability (p). The density can be estimated by dividing abundance (n) by a fixed-radius area.

For the analysis of habitat associations, continuous variables were standardized by dividing their value by twice the standard deviation (Vaughn, 2008). We also tested correlations among habitat variables to avoid multicollinearity using Spearman's correlation coefficients and removed one of each pair where the correlation coefficient was $\geq .6$. Following this, we eliminated the proportion of pine forest, proportion of oak and chestnut trees, and basal area from the same models.

To model abundance, the global model was adjusted according to three different distributions (i.e., negative binomial, Poisson, and zero-inflated Poisson) and differing values for the upper limit of integration (K). All global models were then tested for goodness of fit by means of a Pearson chi-square test (MacKenzie & Bailey, 2004) using parametric bootstrap resampling (1,000 resamplings). Abundance with site covariates was then modeled using a negative binomial distribution ($c\text{-}hat = 1.04$) while setting the detection probability constant over all three-survey periods. The models were ranked using second-order Akaike's information criterion (AIC_c; Akaike, 1998). We considered models competitive for inference if model $\Delta AIC_c \leq 2$. Model averaging was employed to obtain averaged estimates (Burnham & Anderson, 2003). We performed the analysis using R version 3.4.0 (R Development Core Team, 2008) using N-mixture models with the "unmarked" package (Fiske & Chandler, 2011) and model averaging with the "MuMIn" package (Bartoń, 2013).

Population Estimates

Based on our surveys, the lowest elevation at which the nuthatch was detected was 1,192 m above sea level and the highest 1,738 m (see later): However, the highest elevation of any historical record in Thailand was 1,951 m (Deignan, 1946). Thus, we constructed two estimates based on the observed and historical data to estimate the upper limit of the population size.

No nuthatches were detected closer than 4 km to any village, nor closer than 300 m to any agricultural area. Thus, areas within a 4-km buffer of villages and 300 m buffer of agriculture areas were removed from the analysis. Forest patches smaller than 19.7 ha were also not considered as suitable habitat because they were smaller than the estimated breeding home range of a male Giant Nuthatch (Techachoochert, 2018).

A final minimum convex polygon (MCP) covering all historical sites, recently discovered sites and areas considered to comprise suitable habitat was generated, with the addition of a 300 m buffer around its margin. The areas of hill evergreen forest and pine forest within our accepted elevational limits within the buffered MCP were extracted from the RFD map using ArcGIS. The estimated population of Giant Nuthatches in Thailand was then calculated by multiplying the estimated total suitable habitat area by the average density derived from the point surveys described previously.

Results

Abundance and Habitat Associations

We detected Giant Nuthatches at 12 of the 42 sample points (28.6%) during a total of 126-point survey sessions that involved a total of 19 detections, across an elevation range of 1,192 to 1,738 m above sea level. The detections at each of the 12 locations were taken to constitute a presumed territory or pair. These were clustered within four major localities (Figure 1), namely, Doi Ang Khang Royal Project Center (two territories), Doi Chiang Dao Wildlife Sanctuary (three territories), Doi Lang (an outlier of the present-day Doi Pha Hom Pok National Park; five territories), and Mae Ngai

Watershed Station (two territories). All but four sightings were from within protected areas (national parks or wildlife sanctuaries). In contrast, the nuthatch was not detected during our survey from four historical localities where previously detected during 1930 to 1997 (Doi Inthanon National Park, Doi Langka (on the common border of Khun Chae National Park and Jae Sorn National Park), Doi Pha Hom Pok (the core area of Doi Pha Hom Pok National Park), and Khun Mae Ya Watershed Management Unit (part of Huai Nam Dang National Park; Table 1).

We generated a set of 24 regression models to explain the abundance of Giant Nuthatch (Table 3). Five of the 24 models were competitive for inference ($AIC_c \leq 2$). The most supported five models were averaged to estimate the coefficients of those variables (Table 4). The model-averaged coefficients indicated that the abundance of the nuthatch increased with increasing elevation, increasing proportion of hill evergreen forest, and greater distance from villages.

Table 3. Rankings of N-Mixture Models Using Site and Landscape Variables to Explain the Abundance of Giant Nuthatch (λ) and Their Probability of Detection (p) at 42 Sample Sites in Northern Thailand, Surveyed October to November 2015.

Model	*K*	AICc	ΔAICc	ω_i
λ (Elev) p (.)	4	110.83	0	0.16
λ (Elev + Evg) p (.)	5	110.86	0.03	0.16
λ (Evg) p (.)	4	110.88	0.05	0.16
λ (Elev + Evg + Village) p (.)	6	110.98	0.15	0.15
Null	3	112.74	1.91	0.06
λ (Village) p (.)	4	113.14	2.31	0.05
λ (Elev + Evg + BA) p (.)	6	113.47	2.64	0.04
λ (BA) p (.)	4	113.51	2.69	0.04
λ (Elev + Evg + Village + BA) p (.)	7	113.74	2.91	0.04
λ (Tree) p (.)	4	113.81	2.98	0.04
λ (Pine) p (.)	4	114.28	3.45	0.03
λ (Oak) p (.)	4	114.76	3.93	0.02
λ (Height) p (.)	4	115.12	4.30	0.02
λ (Aspect) p (.)	6	116.64	5.81	0.01

Note. Columns indicate AIC adjusted for small sample size (AICc), delta AICc (ΔAICc), AICc weight (ω_i), and number of parameters (*K*). Variables are defined in Table 2. AIC = Akaike's information criterion.

Table 4 . Model-Averaged Parameter Estimates, *SE*s, and 95% CIs for Abundance (λ) of Giant Nuthatch in 42 Sample Sites in Northern Thailand, October to November 2015.

	Estimate	*SE*	95% CI
λ (Intercept)	−0.864	0.507	[−1.371, −0.357]
λ (Elev)	0.535	0.315	[0.220, 0.850]
λ (Evg)	0.517	0.291	[0.226, 0.808]
λ (Village)	0.453	0.285	[0.168, 0.738]

Note. Variables are defined in Table 2. CI = confidence interval; *SE* = standard error.

Population Estimates

We obtained a mean abundance per site of 0.55 Giant Nuthatches with a detection probability of $.287 \pm .145$. Assuming a territory size of 19.7 ha and a detection area of 0.28 km^2 based on a 300-m detection radius (see "Methods" section), the density of Giant Nuthatch in suitable habitat was estimated at 1.96 birds/km^2.

Within the MCP of the likely historical or present range (Figure 2), the total forest cover of hill evergreen and pine forest within the elevational range in which we detected Giant Nuthatch, 1,192 to 1,738 m, was estimated at 448.2 km^2. Thus, the estimated Giant Nuthatch population in Thailand was 878 individuals. However, if an upper elevational limit of 1,951 m is assumed, taking into account three specimens collected at that elevation from Doi Pha Hom Pok (Deignan, 1946), this would yield an estimated potential habitat area of 491.8 km^2 and a slightly larger population, 964 individuals.

Discussion

Distribution and Population Estimates

In our study, Giant Nuthatch was found at 12 of the 42 sample points at four different major localities. Our findings indicate that the nuthatch occurred in a relatively restricted, patchy habitat, and at low density. Due to its low calling rate and limited response to playback, detection during field surveys was problematic. The estimated probability of detection was low, .287, even with tape playback in habitat thought to be favored by Giant Nuthatch.

Giant Nuthatch was not detected at four known historical locations which are present-day protected areas (Table 1). We think it likely that the bird was extirpated from one of these, Doi Inthanon National Park, where the latest specimen record was in 1931, by habitat loss and human settlement before the national park was established in 1972 (Dearden, Chettamart, Emphandu, & Tanakanjana, 1996). Although there has been some regeneration of pine and hill evergreen in recent decades, Giant Nuthatch has not recolonized the site.

The Giant Nuthatch was likely already extirpated from a fifth site, Doi Suthep-Pui National Park several decades ago. No fewer than 10 specimens were collected from Doi Suthep-Pui during 1928 to 1933 (Table 1) and an 11th specimen, collected in 1967 (THNHM-B-07457, original number TISTR 53–793) was the last recorded. We did not resurvey Doi Suthep-Pui as multiple surveys over the past 50 years, most particularly during 1978 to

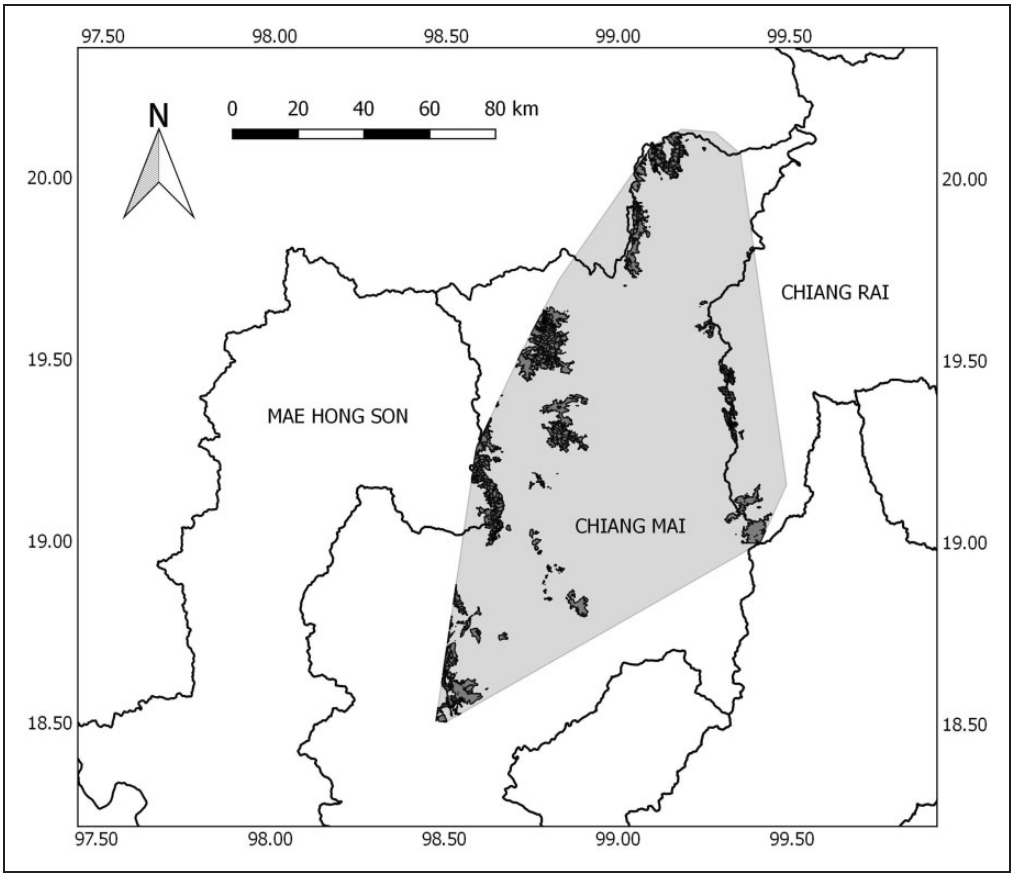

Figure 2. Map of northern Thailand showing suitable habitat of Giant Nuthatch (black) within a minimum convex polygon of historical limits of its range (gray).

1983 (Round, 1984) and subsequently, failed to reveal any Giant Nuthatches.

The population estimate of Giant Nuthatch in Thailand was a maximum of 964 individuals based on an average density of 1.96 individuals/km^2 in approximately 491.8 km^2 of hill evergreen forest and pine forest at elevational range between 1,192 m and 1,951 m. However, even this may overestimate the size of the population in Thailand for reasons that we outline later.

Habitat Associations

The habitat-use model suggested that Giant Nuthatch abundance increased with increasing proportion of hill evergreen forest, increasing elevation, and greater distance from villages. The avoidance of villages is no surprise, as areas closer to villages are subject to higher incidence of fire damage and habitat fragmentation (Bezuijen et al., 2010; Pattanavibool & Dearden, 2002). Remaining forest patches in the vicinity of villages may be too small or too degraded to hold any nuthatches.

Our results only suggest broadscale habitat associations because neither forest cover maps nor available satellite images were sufficiently accurate to take account of the microscale variation in the habitat important to the nuthatch. In Thailand, Giant Nuthatch appears to be restricted to a drier subtype of more open hill evergreen forest, dominated by oak and chestnuts, in which *P. kesiya* is frequent (Matthysen, 1998; Round, 1983) and is usually absent from denser, closed canopy moist evergreen forest lacking pines, which constitutes a significant proportion of the total estimated area of hill evergreen forest. The lack of accurate habitat cover maps that reliably distinguish between drier, more open hill evergreen forest that contain pines, and moister, more closed forest, still classified as *hill evergreen* was a limitation of our study. Without habitat maps of much finer resolution, we cannot safely say by how much we may have overestimated the area of potentially suitable habitat and therefore the size of the Giant Nuthatch population.

The distribution of *P. kesiya* is clearly associated with dry ridges and nutrient-poor soils (Kiianmaa, 2005; Pousujja, Granhof, Willan, & Graudal, 1986; Santisuk, 1997). Such areas are fire prone although under natural conditions, dry-season fires are of low-to-moderate

frequency. Areas closer to villages may burn annually, as local residents use fires to aid nontimber forest product collection, and in clearance for agriculture, and hunting (Phairuang, Hata, & Furuuchi, 2017). Too frequent fires kill *P. kesiya* seedlings which do not develop fire resistance until about 5 years of age (Pousujja et al., 1986; Turakka, Luukkanen, & Bhumibhamon, 1982). In addition, resinous wood is repeatedly hacked from the trunks of mature pines for kindling either for home use or for sale. This makes mature pines more vulnerable to fire and to wind damage: such trees eventually fall (Savage, 1994). Therefore, forest structure in human-used areas is adversely affected by both low recruitment of young pines and the destruction of mature pines which leads to a relatively uniform age structure among remaining pine stands (Savage, 1994; Turakka et al., 1982). Although quantitative data are lacking, the possible disappearance of the Giant Nuthatch population at Kalaw, Shan State, Myanmar, where the pine forests have been subjected to extensive clearance and burning for many decades, has been attributed to habitat degradation and, in particular, the loss of mature pines (Bezuijen et al., 2010). Thus, the effects of frequent fires on the Giant Nuthatch and other threatened species that share the same habitat require urgent further study.

Implications for Conservation

A relatively high proportion (55%) of the montane habitat of Giant Nuthatch in Thailand is already protected (as national park or wildlife sanctuary) in comparison with other Giant Nuthatch range countries. This might suggest that its population in Thailand, though small, is relatively secure. However, as we have shown Giant Nuthatch has probably been lost from as many as five historical sites inside protected areas, almost certainly due to degradation and fragmentation of its preferred habitat.

Although montane habitats are naturally fragmented on ridges and mountaintops, expanding cultivation and upland development increases the level of habitat isolation and reduces patch size (Burgess, Sharpe, & Bruner, 1981). Zeng, Estes, et al. (2018) and Zeng, Gower, et al., (2018) have shown that the rate of annual upland forest loss in northern Thailand has accelerated since year 2000, notwithstanding the establishment of protected areas, due mainly to increased market-oriented growing of corn, especially as animal feed. Clearance took place both inside and outside national parks and other protected areas. Zeng, Estes, et al. (2018) rigorous assessment of forest loss across South East Asian uplands during 2000 to 2014 showed that simulations of forest loss based on United Nations Food and Agriculture Organization statistics underestimated actual forest loss by 36%.

The relative magnitude of the decline in population size of birds and mammals due to habitat fragmentation is often greater than expected from habitat loss alone, with those that are habitat specialists suffering more than habitat generalists (Andrén, 1994). Menon, Soberon, and Peterson (2008) suggested that Asian nuthatches in general showed low proportionate range filling which they attributed to fragmented montane habitats limiting their ability to disperse. The continued degradation of native forest containing stands of mature pines both inside and outside protected areas presents a major threat to the survival of the Giant Nuthatch.

Conservation of the Giant Nuthatch in Thailand will depend on rigorous protection of native hill evergreen forest in its favored zone (~1,100 to 1,900 m) so as to restrict upland development and agricultural expansion and enable presently fragmented habitat patches to gradually coalesce into larger units. A more rigorous system of fire suppression that seeks to limit the extent of burning of both broad-leaved and pine forests, combined with a system of tracking the frequency and intensity of fires, implemented by forest management authorities, will likewise be essential for the long-term management of Giant Nuthatch habitat in Thailand. The existing prohibition on firewood collection in protected areas should be more strictly enforced and extended to a ban on the collection of firewood or kindling from all native forest patches.

While our upper estimate of 964 Giant Nuthatch individuals in northern Thailand might accord tolerably with BirdLife International's (2016) global population estimate of 1,000 to 2,499 individuals, shared among three countries, we remain cautious about our baseline estimate, which may be overly optimistic due to our inability to distinguish the patchy microhabitat of the species within areas of hill evergreen forest. More intensive study with higher resolution multispectral imagery to precisely delineate areas of suitable nuthatch habitat is also needed.

An occupancy survey of the forest patches that we identified would be labor-intensive but would further refine our population estimate. Furthermore, we also urgently recommend further surveys of potential Giant Nuthatch sites in China and, especially, Myanmar, where the areas of suitable montane uplands in the Shan States are potentially quite large (~1,600 km^2). This would enable better assessment of habitat conditions and update knowledge of its distribution and global population. An assessment of long-term threats and the likely impact of climate change on montane biota should be considered for further study.

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References

Akaike, H. (1998). Information theory and an extension of the maximum likelihood principle. In E. Parzen, K. Tanabe, & G. Kitagawa (Eds.), *Selected papers of Hirotugu Akaike* (pp. 199–213). New York, NY: Springer.

Andrén, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: A review. *Oikos*, *71*(3), 355.

Avery, T., & Burkhart, H. (2015). *Forest measurements* (4th ed.). New York, NY: McGraw-Hill.

Bartoń, K. (2013). *MuMIn: Multi-model inference. R package version 1.9. 13*. Vienna, Austria: The Comprehensive R Archive Network.

Bezuijen, M. R., Eaton, J. A., Gidean, R. O. H., & Rheindt, F. E. (2010). Recent and historical bird records for Kalaw, eastern Myanmar (Burma), between 1895 and 2009. *Forktail*, *26*(26), 49–74.

Bibby, C. J., Burgess, N. D., & Hill, D. A. (1992). *Bird census techniques*. London, England: Academic Press.

BirdLife International (2001). *Threatened birds of Asia: the BirdLife International Red Data Book*. Cambridge, UK: BirdLife International

BirdLife International (2016). *Sitta magna*. The IUCN Red List of Threatened Species 2016: e.T22711228A94284869. doi:10.2305/IUCN.UK.2016- 3.RLTS.T22711228A94284869.en

Burgess, R. L., Sharpe, D. M., & Bruner, M. C. (1981). *Forest island dynamics in man-dominated landscapes*. New York, NY: Springer.

Burnham, K. P., & Anderson, D. R. (2003). *Model selection and multimodel inference: A practical information-theoretic approach*. New York, NY: Springer.

Charonthong, K., & Sritasuwan, N. (2009). Behavior of the Giant Nuthatch (*Sitta magna*). *Research Journal of Biological Sciences*, *4*(11), 1142–1147.

Charuphat, T. (2000). Remote sensing and GIS for tropical forest management. In *Proceedings of the Ninth Regional Seminar on Earth Observation for Tropical Ecosystem Management, Khao Yai, Thailand* (pp. 20–24). Khao Yai, Thailand: The National Space Development Agency of Japan, Remote Sensing Technology Center of Japan, RFD, and GIS Application Center/AIT, Khao Yai National Park Thailand

Cropper, M., Griffiths, C., & Mani, M. (1999). Roads, population pressures, and deforestation in Thailand, 1976–1989. *Land Economics*, *75*(1), 58–73.

Dearden, P., Chettamart, S., Emphandu, D., & Tanakanjana, N. (1996). National parks and hill tribes in northern Thailand: A case study of Doi Inthanon. *Society and Natural Resources*, *9*(2), 125–141.

Deignan, H. G. (1946). *Note on birds of Northern Siam: Notulae Naturae of the Academy of Natural Science of Philadelphia* (no. 173). Philadelphia, PA: Academy of Natural Sciences.

Fiske, I., & Chandler, R. (2011). Unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software*, *43*(10), 1–23.

Fox, J., Krummel, J., Yarnasarn, S., Ekasingh, M., & Podger, N. (1995). Land-use and landscape dynamics in northern Thailand: Assessing change in three upland watersheds since 1954. *Ambio*, *24*(6), 328–334.

Fox, J., & Vogler, J. B. (2005). Land-use and land-cover change in Montane Mainland Southeast Asia. *Environmental Management*, *36*(3), 394–403.

Harrap, S., & Quinn, D. (1996). *Tits, nuthatches and treecreepers*. London, England: Christopher Helm.

Kiianmaa, S. (2005). *Natural regeneration and ecological succession in Pinus kesiya watershed plantations in northern Thailand: Implications on plantation management* (Doctoral dissertation), Helsingfors universitet, Helsinki, Finland.

Lekagul, B., & Round, P. D. (1991). *A guide to the birds of Thailand*. Bangkok, Thailand: Saha Karn Bhaet.

MacDonald, M. A. (2003). The role of corridors in biodiversity conservation in production forest landscapes: A literature review. *Tasforests-Hobart*, *14*, 41–52.

MacKenzie, D. I., & Bailey, L. L. (2004). Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics*, *9*(3), 300–318.

Matthysen, E. (1998). *The Nuthatches*. London, England: T & AD Poyser.

Maxwell, J. F. (2004). A synopsis of the vegetation of Thailand. *The Natural History Journal of Chulalongkorn Univeristy*, *4*(2), 19–29.

Menon, S., Soberon, J., & Peterson, A. T. (2008). Preliminary analysis of the ecology and geography of the Asian nuthatches (Aves : Sittidae). *The Wilson Journal of Ornithology*, *120*(4), 692–699.

Pattanavibool, A., & Dearden, P. (2002). Fragmentation and wildlife in montane evergreen forests, northern Thailand. *Biological Conservation*, *107*(2), 155–164.

Phairuang, W., Hata, M., & Furuuchi, M. (2017). Influence of agricultural activities, forest fires and agro-industries on air quality in Thailand. *Journal of Environmental Sciences (China)*, *52*, 85–97.

Pousujja, R., Granhof, J., Willan, R. L., & Graudal, L. (1986). *Pinus kesiya Royle ex Gordon. Seedleaflets; No. 5*. Humlebaek, Denmark: Danida Forest Seed Centre.

R Development Core Team. (2008). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Rerkasem, K. (1998). Shifting cultivation in Thailand: Land use changes in the context of national development. In *ACIAR proceedings* (pp. 54−63). Canberra, Australia: Australian Centre for International Agriculture.

Riley, J. H. (1938). Birds from Siam and the Malay Peninsula in the United States National Museum Collected by Drs. Hugh M. Smith and William L. Abbott. *US Natl Mus Bull, 172*. Washington DC: Smithsonian Institution

Robson, C. (2000). *A guide to the birds of Southeast Asia: Thailand, Peninsular Malaysia, Singapore, Myanmar, Laos, Vietnam and Cambodia*. Princeton, NJ: Princeton University Press.

Round, P. D. (1983). Some recent bird records from northern Thailand. *Natural History Bulletin of Siam Society*, *31*(2), 123–138.

Round, P. D. (1984). The status and conservation of the bird community in Doi Suthep-Pui National Park, north-west Thailand. *Natural History Bulletin of Siam Society*, *32*(1), 21–46.

Royle, J. A. (2004). N-mixture models for estimating population size from spatially replicated counts. *Biometrics*, *60*, 108–115.

Santisuk, T. (1988). An account of the vegetation of northern Thailand. *Geological Research*, *5*, 1101.

Santisuk, T. (1997). Geographical and ecological distributions of the two tropical pines, *Pinus kesiya* and *Pinus merkusii*, in Southeast Asia. *Thai Forest Bulletin (Botany)*, *25*, 102–123.

Savage, M. (1994). Land-use change and the structural dynamics of *Pinus kesiya* in a hill evergreen forest in northern Thailand. *Montain Research and Development*, *14*(3), 245–250.

Smitinand, T. (1977). *Vegetation and ground cover of Thailand* (Technical Paper No. 1). Bangkok, Thailand: Kasetsart University.

Techachoochert, S. (2018). *Population size and ecology of Giant Nuthatch (Sitta magna)* (Unpublished doctoral dissertation). Mahidol University, Bangkok, Thailand.

Turakka, A., Luukkanen, O., & Bhumibhamon, S. (1982). Notes on *Pinus kesiya* and *P. merkusii* and their natural regeneration in watershed areas of northern Thailand. *Acta Forestalia Fennica*, *178*, 5–31.

Vaughn, B. K. (2008). Data analysis using regression and multilevel/hierarchical models, by Gelman, A., & Hill, J. *Journal of Educational Measurement*, *45*(1), 94–97.

Werner, W. L., & Santisuk, T. (1993). Conservation and restoration of montane forest communities in Thailand. In H. Lieth & M. Lohmann (Eds.), *Restoration of tropical forest ecosystems* (pp. 193–202). Dordrecht, the Netherland: Springer.

Zeng, Z., Estes, L., Ziegler, A. D., Chen, A., Searchinger, T., Hua, F., . . . Wood, E. F. (2018). Highland cropland expansion and forest loss in Southeast Asia in the twenty-first century. *Nature Geoscience*, *11*, 556. doi:10.1038/s41561-018-0166-9

Zeng, Z., Gower, D. B., & Wood, E. F. (2018). Accelerating forest loss in Southeast Asian Massif in the 21st century: A case study in Nan Province, Thailand. *Global Change Biology*. doi:10.1111/gcb.14366