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Long term stability of White-necked Picathartes population in south-east Sierra Leone

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Summary

White-necked Picathartes *Picathartes gymnocephalus* is a globally 'Vulnerable' bird endemic to the highly threatened Upper Guinea forests in West Africa. In an environment under a high level of threat, the high breeding site fidelity (or breeding site persistence) of this species enables long term monitoring of colony site occupancy, colony size and other breeding parameters, which provide multiple indicators of population status. We surveyed known colony sites and searched for new sites in three recent breeding seasons in order to assess the current population status in the most important part of their range in Sierra Leone, the Gola Forest. We found 157 active nests at 40 colonies, equating to at least 314 adult birds. Less than half of the known colonies were protected by the Gola Forest Reserve. Colonies outside the reserve tended to be confined to larger rocks and subject to disturbance from human activities in close proximity, but did not have fewer active nests in them. Colonies outside the reserve were also more likely to be inactive in a given year whereas all colonies inside the reserve were active in every survey year. A predictive distribution model indicated that the survey region could have as many as 234 nests equating to at least 468 breeding birds. There was no evidence that mean colony size had declined since surveys undertaken in the 1980s and 1990s but it was not possible to compare colony abandonment rates inside and outside the reserve over that time period. Clutch and brood sizes were similar in each year, though brood size appeared slightly lower in the third survey year possibly because of a slightly later survey date. Mean clutch and brood sizes reported during the study period were similar to those found in the 1980s and 1990s. We conclude that the population of White-necked Picathartes in the Gola Forest area has been relatively stable over the last two decades, reflecting both the efficacy of protection afforded by the Gola Forest Reserve and presumably low pressure to farm new areas in the nearby community forest. However, regular monitoring of colonies both inside and outside the reserve is required to detect any systematic impact on the birds as pressure for land increases.

Introduction

Medium and long-term population trends of birds underlie much conservation priority setting, especially assessments of threat status (BirdLife International 2000). The direct monitoring of population sizes over time is seldom feasible for many tropical forest birds due to low densities, which make robust estimates of population levels hard to achieve. However, species breeding in stable colonies are more amenable to monitoring because such aggregations can be easier to detect than lone birds, can be revisited from year to year, and can provide information about reproductive success, which is also typically hard to acquire for tropical forest birds (Stutchbury and Morton 2001). The White-necked Picathartes *Picathartes gymnocephalus* is one of very few colonial-nesting forest birds in the Upper Guinea forests of West Africa with high breeding site fidelity, hence providing a valuable opportunity to track the status of a forest species over time in what is a severely threatened habitat (Mittermeier *et al.* 2004).

The White-necked Picathartes is a restricted-range species endemic to Upper Guinea rainforests. Its distribution is highly fragmented with small, scattered populations in only five West African countries (Guinea, Sierra Leone, Liberia, Ivory Coast, and Ghana; BirdLife International 2009). Available census data on breeding numbers suggest that the total population size is less than 10,000 individuals, which, together with the rapid degradation of Upper Guinea forests, classifies the species as 'Vulnerable' (BirdLife International 2009). Its peculiar ecology and nesting biology has been documented in detail in Sierra Leone (Thompson 1997, 2001, 2004a,b). It is a monogamous species that breeds predominantly in small colonies (2–5 pairs) on rock-faces under forest canopy (Thompson 1997). The species is apparently dependent on the proper management of forest reserves where active colonies occur (BirdLife International 2009). Consequently, the substantial number of breeding sites that lie outside protected areas where disturbance is high (i.e. within forested habitats used by local communities) and with detrimental land management (i.e. forest degradation) are at risk.

In Sierra Leone, the total number of White-necked Picathartes was estimated at 1,080 individuals in 1994 (Thompson 1997, Thompson *et al.* 2004). Active colonies were known from at least six forest reserves, with the largest numbers recorded in the Gola Forest and the nearby Kambui Hills (Thompson 1997). Based on the work of Allport *et al.* (1989) and his own survey, Thompson (1997) estimated that Gola Forest supported a minimum of 152 active nests across at least 36 colony sites in 1994[1]. This is the largest known concentration of White-necked Picathartes in Sierra Leone, and one of the largest in West Africa (Thompson 1997).

There has been no census of White-necked Picathartes colonies in south-east Sierra Leone since a protracted period of internal conflict (1992–2002). Forest clearance for farming is thought to be the main factor causing colony site abandonment (Collar and Stuart 1985, Thompson 1997) presumably through direct disturbance, exposure to weather and predation or isolation from suitable foraging habitat. While there is some evidence that the war had little negative impact on some species in the Gola Forest area (e.g. Lindsell *et al.* 2011), the current status of White-necked Picathartes is unknown. Recent observations from the Western Area Peninsula forest in south-west Sierra Leone, where illegal deforestation has been long reported (Thompson 1993), suggest that colony desertion is ongoing. Of eight colony sites supporting 18 active nests reported during a pre-war survey in 1991–1992 (Thompson 1997), only five sites with a total of eight active nests were still used by 2008 (Okoni-Williams *in litt.*). Within the Gola Forest area, a high proportion of colonies are within community forest without formal protection (Allport *et al.* 1989, Thompson 1997), so are presumably under greater threat, though this is not certainly known. Understanding the conditions that lead to colony desertion may lead to practical management recommendations to reduce abandonment rates.

Despite intensive work in the past, it is clear from a distribution map that not all colonies in the Gola Forest area are likely to have been discovered. Although breeding sites are far easier to find than the birds themselves, nonetheless most sites to date have been found by researchers through local informants. Their distribution therefore partly reflects the distribution of human population. The true density of colonies is likely to be somewhat higher, and knowing this is important for estimating actual population size as well as the relative contribution of declining sites to the overall population trajectory. Given the historic importance of the Gola Forest area for this species and past work in the region (Thompson 1997), a reappraisal of its status was needed. This would not just consider existing colonies, but attempt to identify new, previously unidentified colonies.

We collected data on breeding activity and associated habitat covariates at 40 active colony sites in the Gola Forest Reserve and nearby community forests, during three recent breeding seasons. Specifically, we:

[1]Higher figures of 47 colony sites and 190 nests (Fry and Keith 2000; Thompson and Fotso 1995) or 204 nests (Thompson *et al.* 2004) are reported elsewhere. The larger number of colonies includes those thought to be abandoned. The figure of 204 nests arose from an adding error in Thompson (1997) and should have been 152 (H. Thompson *in litt.*).

1. Reviewed the current status of the population in this key area and compared this with historical census data collected between 1988 and 1994,
2. Assessed the effect of habitat destruction and human disturbance on the species, by comparing colony survival and current breeding activity (a) between sites located inside and outside the Gola Forest Reserve, and (b) between sites presenting various levels of human disturbance,
3. Examined between-year variation in breeding activity to provide insight into the population dynamics of the species,
4. Used predictive modelling to identify candidate areas that may support currently unknown colony sites of the species across the Gola Forest Reserve and provided an estimate of the total population size in the reserve which accounts for incomplete detection.

Materials and Methods

Study period, study area and location of colony sites

White-necked Picathartes colonies in the Gola Forest Reserve and surrounding areas were surveyed in three breeding seasons (21 October 2006 to 21 January 2007; 02 October 2008 to 21 February 2009; 07 December 2009 to 06 February 2010). The set of colony sites monitored during the first season was established from published sources (Allport *et al.* 1989, Thompson 1997), through consultation with experienced field staff and from interviews conducted in villages around the Gola Forest (Figure 1). In subsequent years, further colonies were added from local knowledge. Occupied rock faces less than 100 m apart were considered part of the same colony during data analyses. Due to logistic constraints, not all known sites were surveyed each year (see Results and Appendix 1).

Colony site characteristics

Colony site characteristics and physical attributes of rock-faces used by the species were collected at active colony sites (Table 1). These included: (1) slope of the terrain measured with a clinometer and distances to (2) the nearest stream and (3) the reserve boundary (only for colony sites located inside the actual Gola Forest Reserve) estimated using GPS. Evidence of human activities such as farming, hunting and logging was recorded in a radius of c.200m around each colony site which is well within the area thought to be used by colony members (Siaka 1998). This information was subsequently used to assign each colony to one of the following categories: (1) "no disturbance" when no evidence was found, (2) "past disturbance" when human activities were detected but had long ceased (e.g. commercial logging in the Gola Forest), and (3) "current disturbance" when the evidence suggested the recent impact of human activities. Each nesting surface was measured

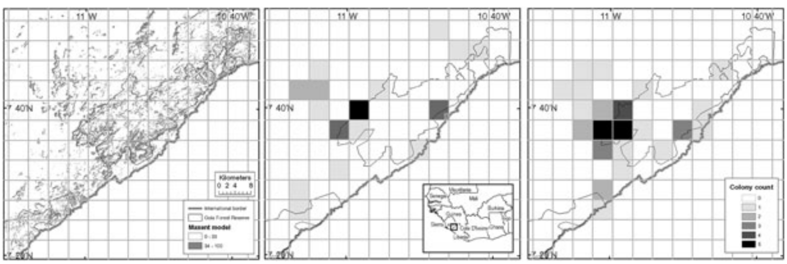

Figure 1. Locations of White-necked Picathartes colonies in the Gola Forest region (n = 40 sites; see also Appendix 1). Left: Shaded areas indicate areas of predicted high occupancy likelihood from a Maxent model based on known colony locations; Centre: Colony locations from Allport et al. (1989); Right: Colony locations in 2010

Table 1. Colony site characteristics and physical attributes of rock faces used by White-necked Picathartes in and around the Gola Forest Reserve

Variable	Mean (SE)	Range	Sample size
1. Colony site characteristics			
Slope (degrees)	22.5 (3.0)	11–40	10
Distance to stream (m)	194 (43)	1–997	25
Distance to Forest Reserve boundary (m)[1]	1,309 (274)	85–2,920	16
2 Rock face characteristics			
Rock face width (m)	8.0 (0.6)	2.5–15.0	39
Rock face height (m)	7.8 (0.6)	3.6–20.0	30
Rock face slope from horizontal (degrees)	67.5 (5.7)	30–90	10
Rock face bearing (degrees)	216.4 (13.0)	88–340	30

[1]Only for sites located inside the Gola Forest Reserve.

(width and height) using tape measures and calibrated poles. The bearing and the rock-face angle from horizontal were recorded using a clinometer. Notes were made on features that may hinder nesting (vegetation over the rock-face, moss on the rock-face, water draining across the rock face).

Breeding activity

In Sierra Leone, the breeding season spans eight months: egg-laying occurs between June and December, and chick-rearing between August and February (Thompson 2004b). We monitored White-necked Picathartes colonies between October and February, which corresponds to the period of peak breeding activity (Thompson 1997). However, due to a protracted breeding season, direct counts of nests with eggs or chicks on a single survey visit do not provide a reliable estimate of the number of breeding pairs. To account for this, nests with indirect signs of breeding activity were also counted.

Each colony site was visited by a team of two to four trained observers, keeping the duration of data collection to a maximum of 45 minutes and avoiding the early morning and late afternoon periods (during the peak periods of adult activity at the colony) in order to minimise disturbance. Each nest was assigned to one of the following categories: (1) broken (old nests), (2) incomplete under construction, and (3) complete. We then checked the subset of incomplete and complete nests for direct signs of breeding activity (eggs or young in the nest) or indirect signs (presence of fresh mud on the nest, an adult bird in the nest but with no egg/chick, fresh lining, faecal remains on the nest or feathers/eggshell pieces inside or below the nest). Clutch size or the number of chicks in each occupied nest was recorded. Nearest Neighbour Distance (NND) was measured as an index of the relative density of nests on the rock-face.

Modelling likelihood of occupancy across the study area

A spatially explicit predictive model of the likelihood of colony occurrence was developed to focus searches for further colonies in the large areas of the reserve that remain unexplored. Maximum entropy modelling was used to predict the likelihood of occurrence of nests as a function of Normalised Vegetation Difference Index (NDVI), which is a measure of vegetation net primary productivity, land cover (forest / non forest) and topography (slope) using Maxent 2.3.1 (Phillips *et al.* 2006, Phillips and Dudik 2008). NDVI was calculated (B4-B3/B4+B3) from Landsat TM imagery (path 200, row 55, 15/1/2007). Forest cover was taken from 2003 (Klop *et al.* 2008). Slope was calculated in Imagine 8.5 (ERDAS Inc. 2001) from 90 m Shuttle Radar Topography Mission SRTM (USGS 2004; Global Land Cover Facility, University of Maryland, College Park, Maryland, February 2000; www.landcover.org). The default settings in Maxent were used. This meant that the characteristics of the explanatory variables at the locations where birds were known to be present were compared to those at 10,000 randomly generated pseudo-absence points. The distribution with the maximum entropy (i.e. most spread out) within the constraints of the model was then calculated. The coordinates of known colony sites were used to train the model, weighted by the number of nests at each colony, such that colonies used by a greater number of birds contributed more to the analysis. The area under the ROC curve (AUC), which measures the quality of a ranking of sites was used to assess model performance. This is the probability that a randomly chosen presence site will be ranked above a randomly chosen absence site. A score of 1 would indicate that all presence points were correctly mapped as such, while 0.5 indicates that points were identified as occupied with the same accuracy as expected by chance alone. The equal model sensitivity (no. of true positives) and specificity (no. of false positives) threshold was used as one cut-off to transform the continuous output into a binary map of occupied or unoccupied points. The consistency of the model at predicting likely occupancy was tested by repeating the model process 100 times, omitting different pairs of points each time. The standard deviation around the average area calculated to be suitable (based on the equal specificity and sensitivity threshold) was used as a quantification of consistency.

The value of the model and its potential suitability for use in further analysis was determined by field work, with surveyors searching for colonies in areas with varying predicted likelihood of occupancy.

Population estimate and model usage

To estimate the population in the Gola Forest Reserve, we calculated colony density in the areas predicted as potentially occupied by the Maxent model in a 1 km buffer either side of the Reserve boundary and extrapolated this to all areas predicted by the model inside the forest reserve. The +/- 1 km buffer was selected because this is where we believe colony detection has been most complete to date. Colony density was multiplied by the mean colony size of 3.94 (SD = 2.62) (see Results) to produce an overall population estimate for Gola Forest Reserve. The standard deviation (SD) of the Maxent model was combined with the SD of mean colony size to give an overall SD for the estimate.

Data analysis

Descriptive statistics were compiled for nine nesting habitat variables (Table 1). A principal components analysis (PCA) was used to reduce the initial set of habitat variables but due to missing data, only five habitat variables at 19 colony sites were included in the analysis (Table 3). Breeding activity (mean number of active nests and mean NND) was compared between breeding seasons (3 levels: 2007–2008, 2008–2009, and 2009–2010) and between site locations (2 levels: inside and outside the forest reserve) using general linear models (GLMs). Site location and breeding season were considered as fixed effects, while the colony identity was nested as a random factor. To assess differences in timing of monitoring, the dates at which colony sites were visited were compared between breeding seasons using a non-parametric Kruskal-Wallis test. We used one-way ANOVA to test for the effect of human disturbance (three levels; see above) on the mean number of active nests/colony (averaged for the three years). Clutch sizes and brood sizes were also compared between years using Fisher exact tests (due to small samples sizes). Data were analysed with Statistica (StatSoft 2001) and are presented as mean ± SE unless otherwise stated.

Results

Population status

Forty sites (19 in Gola Forest Reserve and 21 in community forest) with at least one active nest present during one breeding season were visited during the study (see Figure 1): 33 sites (109

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nests) in the first survey, 29 (125 nests) in the second survey, including three new sites, and 36 (112 nests) in the third survey, including four new sites (Appendix 1). Because the set of monitored sites differed slightly each year, an estimate of the maximum breeding activity in the Gola Forest area was obtained by selecting the year of highest nest count for each of the 40 sites, which gave a total of 157 nests. Seventy-one of these were inside the Gola Forest Reserve boundary.

Of the 21 colonies surveyed in community forests in at least one of the three survey years, three were inactive during one out of two surveys, three were inactive during one out of three surveys and one was inactive during two out of three surveys. One colony was active only in the first year and not in two subsequent years, so may have been abandoned, but two colonies were inactive in the first year and later found active, so inactive colonies are not necessarily abandoned. Five colonies in community forest were inactive in the final survey year but not certainly abandoned. All colonies in the forest reserve were active in all years that they were surveyed.

In order to compare the annual activity rate between colony sites located in community forest (= unprotected sites) vs. forest reserve (= protected sites), we restricted our analyses to the 26 colony sites that were surveyed during the 3 census years (12 protected sites and 14 unprotected sites; see Appendix 1). Of 42 colony-year surveys in community forest, five recorded no breeding activity, hence the mean annual activity rate of colonies in community forest was 0.88. In the forest reserve, the mean annual activity rate estimated from 36 colony-year surveys was 1 (i.e. all sites active in all years), which was significantly higher than that found in community forest (chi-square test: $\chi^2_1 = 4.58$, $P = 0.032$).

Current colonies were matched with 13 of 21 sites (60%) surveyed in the 1980s (Allport *et al.* 1989) and six of 15 sites (40%) surveyed in the early 1990s (Thompson 1997) (Table 2). Unmatched colonies from former surveys lacked precise information about location or were not found again during this study. None of the matched colonies had been abandoned since the earlier surveys whilst one site, considered abandoned in 1989, was found to be active with one nest recorded in all three years of the current survey. Mean colony size calculated from the highest number of active nests found at a colony during any of the three surveys was 3.93 (0.62) for the whole survey and 4.00 (0.76) for colonies inside Gola Forest Reserve. A comparison of nest numbers at matched colonies between the past surveys and our most recent survey in 2009–2010 found no significant change (paired t-test: $t_{17} = 0.64$, $P = 0.53$; Table 2).

Breeding habitat

Colony site and rock-face characteristics are summarised in Table 1. Colonies tended to be sited on top of hills or on hill slopes (hill top: 48%, valley side: 36%, valley bottom: 16%, $n = 25$), in relatively steep terrain (mean slope = 22.5 ± 3.0 degrees), and generally not far from streams (mean distance = 194 ± 43 m). The size of occupied rock-faces ranged from 2.5 to 15 m wide, and from 3.6 to 20 m high. Occupied rock surfaces were always clear of vegetation and free of surface water. Occupied faces were oriented between north-west and south-east (avoiding north-east facing slopes), and overhanging with a mean angle of 67.5 (± 5.7) degrees off the horizontal (Table 1). Colonies inside the Gola Forest Reserve were frequently found close to the official boundaries of the reserve (mean = 1,309 ± 274 m; Table 1). Around one third of all colonies were found in areas subject to a high level of human disturbance such as logging and farming (current disturbance: 30%, past disturbance: 20%, no disturbance: 50%, $n = 40$).

The PCA using 19 sites for which all data were available resulted in two components that together accounted for c.70% of the total variance (Table 3). Factor 1 (x axis) explained 50% of variance and was positively correlated with rock face size (both width and height) and level of human disturbance, and negatively with distance to stream. Factor 2 (y-axis) explained c.20% of variance and was positively correlated with rock face orientation (Table 3). When plotting the 19 colony sites along these two axes, we found a tendency for segregation between sites inside the Gola Forest Reserve and those in community forest (Fig. 2). The comparison of the site

Table 2. Comparison of picathartes colony sizes (no. of active nests) between different survey periods (ND = no data).

Site code	No. of active nests					Source
	1988-1989	1990-1994	2006-2007	2008-2009	2009-2010	
2	7	3	4	2	2	1, 2
3	5	3	1	1	1	1, 2
38, 39	ND	8	ND	ND	3	1
37	ND	3	1	0	0	1
34	ND	1	1	1	0	1
36	ND	0	1	4	0	1
10	8	ND	13	15	10	2
14	7	ND	1	ND	1	2
32	10	ND	16	18	17	2
31	6	ND	5	3	6	2
27	1	ND	2	3	2	2
21	3	ND	3	5	3	2
5	8	ND	8	5	8	2
6	3	ND	3	4	3	2
33	4	ND	5	7	4	2
30	9	ND	12	14	12	2
24, 25, 26	3	ND	ND	ND	3	2

[1]Thompson (1997): census data collected between March 1990 and February 1994
[2]Allport et al. (1989): census data collected between October 1988 and February 1989

coordinates between the two groups was statistically significant along Factor 1 (t-test: $t_{17} = 2.55$, $P = 0.02$) but not along Factor 2 (t-test: $t_{17} = 1.82$, $P = 0.08$). This suggests that sites in community forest tended to be of larger size, located closer to streams and subjected to higher levels of human disturbance than protected sites.

Breeding activity

Data on nest activity were collected during three breeding seasons (Table 4). Each monitoring period lasted from two to three months with a later median date in 2009–2010 (Kruskal-Wallis $H_2 = 38.3$, $P < 0.001$; Table 4). Since new colonies were discovered each year, the number of sites monitored inside the reserve boundaries increased over time to reach a maximum of 17 in 2009–2010 (Table 4). Direct signs of breeding activity accounted for 12–15% of the total number of active nests found. Most of those nests contained two eggs or two chicks, except in 2009–2010 when brood sizes were lower (2006–2007 vs. 2009–2010: Fisher's exact test $P = 0.01$, and 2008–2009 vs. 2009–2010: Fisher's exact test $P = 0.02$; Table 4).

Table 3. Factor-variable correlations (factor loadings) for a PCA involving five habitat variables (see Table 1) recorded at White-necked Picathartes colony sites ($n = 19$ sites). The percentage of explained variance by each PCA factor is given in parentheses and only factor loadings > 0.7 are significant (bold)

Variable	Factor 1 (47.91%)	Factor 2 (20.89%)
Rock face width	**0.846**	-0.013
Rock face height	**0.929**	-0.031
Rock face bearing	-0.245	**0.926**
Distance to stream	-0.443	0.102
Level of human activity	**0.747**	0.419

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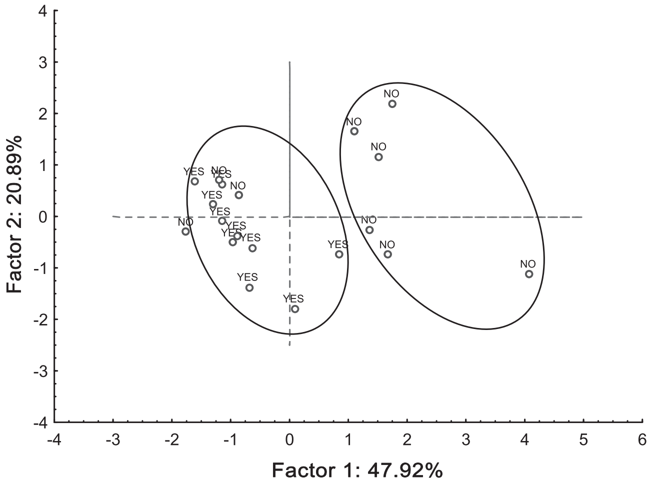

Figure 2. Representation of White-necked Picathartes colony sites along the first two factors of the PCA (n = 19 sites; see Table 3). The two ellipses suggest a tendency for segregation (along Factor 1) between sites located inside the Gola Forest Reserve (label "YES") and those located outside the Gola Forest Reserve (label "NO")

A GLM did not show any difference in active colony size between community forest and forest reserve sites (reserve: 3.7 ± 0.5; community: 3.4 ± 0.6; $F_{1,98}$ = 0.03, P = 0.86). There was, however, a significant effect of year ($F_{2,98}$ = 6.44, P = 0.003), with larger colonies recorded in 2008–2009 (4.3 ± 0.8) when compared to both 2006–2007 (3.3 ± 0.7) and 2009–2010 (3.1 ± 0.6). Neither nearest neighbour distance nor human disturbance significantly influenced colony size (all $P > 0.05$).

Distribution model

The Maxent model produced a map of the likelihood of occupancy by colonies across the study area that had an AUC of 0.947, indicating that the model was good at describing the distribution of colonies (Figure 1). At the equal training sensitivity and specificity threshold of 33.7, the model predicted that 186 km^2 (25.7 %) of the Gola Forest Reserve (as opposed to the wider area) was potentially occupied by a colony (SD = 14.79). In order to narrow the search area and focus on areas of highest likelihood we also used an arbitrarily chosen higher threshold of 55. This was more stringent than the 33.7 threshold and accounted for 59.5 km^2 (7.4%) of the reserve.

Searches for new colonies using the model prediction were made on 11 days in 2009. A path of least resistance was walked for c.15.8 km, but within areas of highest predicted suitability only c.8 km was searched, equating to an area of c.40 ha. Rocks of a size and shape initially thought suitable for picathartes were encountered on nine occasions. All were within areas of predicted high suitability. All other rocks encountered were considered obviously too small, exposed, overgrown or wet. Of the nine, four were occupied by picathartes, holding a total of five new active nests. Due to their proximity in space (< 100 m), two of these rock faces were pooled as a single colony site during the present analyses. Thus, overall, three new colony sites were added to the pool of previously known sites (see Appendix 1).

The density of colonies within a 1 km buffer either side of the reserve boundary was 0.202 km^{-2}. This density predicted 37.57 (SD = 2.99) colonies within the forest reserve, which equated to 148.20 (SD = 99.14) nests. This is 19 more colonies and 77 more nests within the reserve than were known previously and suggests a total in and around Gola Forest of 234 nests.

Table 4. Summary data for three breeding seasons of monitoring White-necked Picathartes colonies in the Gola Forest.

Variable	Breeding season		
	2006–2007	2008–2009	2009–2010
1. Median date of survey (1 Oct. = 1)	03 Nov	27 Nov	08 Jan
2. No. of colonies			
Inside Forest Reserve	12	15	17
Outside Forest Reserve	21	14	19
All pooled	33	29	36
3. Mean No. of active nest/colony (SE; range)			
Inside Forest Reserve	3.9 (0.9)	3.8 (0.9)	3.5 (0.8)
Outside Forest Reserve	3.0 (0.9)	4.9 (1.4)	2.7 (1.0)
All pooled	3.3 (0.7; 0 - 16)	4.3 (0.8; 0 - 18)	3.1 (0.6; 0 - 17)
4. Mean Nearest Neighbour Distance (m) (SE; sample size)			
Inside Forest Reserve	0.9 (0.2)	1.7 (0.3)	1.2 (0.2)
Outside Forest Reserve	2.1 (0.5)	2.2 (0.5)	1.4 (0.2)
All pooled	1.5 (0.3; 20)	1.9 (0.3; 18)	1.3 (0.1; 18)
5. Mean Clutch size (sample size)	1.7 (6)	1.9 (8)	1.9 (9)
6. Mean brood size (sample size)	2.0 (10)	2.0 (7)	1.3 (4)

Discussion

The current assessment of the status of White-necked Picathartes in Gola Forest suggests that:

1. Current breeding population size and colony sizes are similar to those recorded in 1988–1994 and in other parts of their range,
2. Inter-annual differences in level of breeding activity are low, though inter-seasonal differences in mean brood sizes were found,
3. Active sites located in community forest do not support smaller colonies or less tightly packed nests when compared to those located in the forest reserve, despite a higher level of human pressure and habitat degradation in the former area,
4. A lower annual activity rate of colony sites located in community forest was detected because on a substantial number of occasions, colonies located in community forest were found inactive in one or more years, while no inactivity was observed during surveys of colonies in the forest reserve,
5. Nevertheless, the fact that sites were inactive in one or more years demonstrated that inactive sites need to be visited for several years before it can be certain that they are abandoned.

Population size

The overall number of colonies in the Gola area closely matched that known from earlier surveys and mean colony size appeared to have changed little in that time. Mean colony size was similar to two previous censuses conducted by Allport *et al.* (1989) and Thompson (1997) between 1988 and 1994 when 21 and 15 active colony sites, respectively, were found in the Gola Forest region, with a total of 152 active nests, and a mean colony size of 4.2 nests. Mean colony size was also similar to that recorded for this species in Liberia (3.8, $n = 31$; Gatter 1997) and throughout the region (4.2, $n = 115$; Thompson *et al.* 2004). Therefore, we suggest that for those colonies, breeding activity has been notably stable over the two decades. However, we note that no long term comparison could be made for 19 colony sites previously reported by Thompson (1997) and Allport *et al.* (1989) due to imprecise location data in the earlier studies. We also acknowledge that the population estimates and stable trend yielded by our study did not consider the non-breeding component of the population nor levels of productivity, so that actual population trends may slightly differ. More complete surveys may however be more difficult to achieve in dense forests, and while it is not possible to determine accurately population trends without them, surveying occupied nests at colony sites is perhaps the most pragmatic approach to monitor picathartes in the long term. A similar monitoring approach has been used in the closely-related Grey-necked Picathartes *Picathartes oreas* and has proved useful to detect an ongoing downward trend in their population size in southern Cameroon (Awa *et al.* 2009).

During the five years covered by this study, seven sites were found without activity in one or more breeding seasons (Appendix 1). Moreover, after accounting for incomplete survey histories at some sites (i.e. removing sites that were not followed over the entire study period), a lower annual activity rate of colony sites located in community forest was apparent. Since human disturbance is usually high in community forest (see below), this may indicate that those unprotected colonies are at a higher risk of abandonment than those in the forest reserve. As further evidence for this, we note that all currently known sites where breeding activity has long ceased (i.e. long-abandoned sites not included in the present analyses; see also Allport *et al.* 1989) are in community forest ($n = 7$ sites).

During this study some sites were not active in all years, which suggests that an absence of fresh nests in a given year does not necessarily indicate that the site is abandoned. In addition, Allport *et al.* (1989) considered six sites they visited to be abandoned on the basis of having only old, abandoned nests, but our observations suggest that they may just have been temporarily unused (i.e. one site they reported as abandoned was found to be occupied in the present study). We have not yet located any site from the 1980s and 1990s that was occupied then but has had no sign of breeding at all in recent years. It is nevertheless possible that our failure to relocate some colony sites in the present survey is partly because they have been abandoned and that the low rate of abandonment that we report is a product of the survey method.

Field work directed by the model describing the potential distribution of colonies led to the discovery of three new colony sites, the first that have been found in Gola Forest without relying on local information. While an advance over previous knowledge, the model is by definition a simplification and will not describe all of the factors determining colony distribution. For example, the need for rocky outcrops may not explicitly have been accounted for in the model (although these may have been accounted for at least partially by other variables) and as such it could potentially have been improved by considering geological information. Further, a better indication of potential disturbance could be included. However, our model does still appear to have given an indication that there remain more breeding sites to be discovered within the reserve. Although a potential doubling of known colonies inside the reserve may be over-optimistic, the confidence intervals around the model were wide. Nevertheless, we suggest that the extrapolation may be conservative rather than an over estimate because the colony density figure itself may be a substantial underestimate. There may also be new colonies to be found within the unprotected community forests, but the analysis here suggests that the reserve itself is expected to hold the bulk of existing colonies in the region.

The range of White-necked Picathartes within neighbouring Liberia is widespread in the north and north-east of the country (Gatter 1997), but recent surveys on the Liberian side of Gola Forest did not report its presence (Hoke *et al.* 2007) though there seems little reason to think it would be absent from here. The Ghanaian population was suspected to be extinct for over 30 years between the 1960s and its recent rediscovery in 2003 (Marks *et al.* 2004). So despite its relatively obvious habitat requirements, White-necked Picathartes has remained a rather enigmatic species and population levels in all range states are poorly known (Thompson *et al.* 2004). Use of such predictive models may improve efforts to locate new colony sites and the model reported here is currently being used in forests in western Liberia, although with no records to date.

Inter-annual differences in level of breeding activity

Our study is the first to compare breeding activity of White-necked Picathartes across several years. Our observation of greater breeding activity in 2008–2009 (active nests/colony) may reflect the influence of environmental factors. Breeding numbers and reproductive parameters in many bird species are influenced by inter-annual variations in food supply (Newton 1998), which in turn are affected by ultimate factors such as weather conditions. Productivity (chicks fledged/pair) in this species has been previously found to differ strongly between years, which may also reflect inter-annual differences in food abundance (Thompson 1997). The lower mean brood size found in 2009–2010 may perhaps reflect annual changes in food supply conditions, although the observed difference may be explained, at least in part, by variation in survey timing. Colony monitoring was undertaken somewhat later in 2009–2010 (Table 4) compared with the other two years by which time brood reduction, which is common in this species, may already have occurred. To improve the comparability of population estimates and other reproductive measures between breeding seasons, the seasonal monitoring needs to be carried out at the same stage of breeding each year as far as possible.

Protected versus unprotected colonies

Rock-face and habitat characteristics were comparable to those found by Thompson (1997, 2004b) and Allport *et al.* (1989). Noteworthy is the fact that occupied rock faces are never oriented in the NE direction, and are usually sited in relatively steep terrain, not far from water courses. The scarcity of colonies on smaller rocks in community forest may reflect their greater vulnerability to disturbance since small rocks will form less of a hindrance to clearance of forest around them for agriculture. Traditional beliefs by local communities may also influence the conservation of large rock formations on which picathartes nest (Thompson and Fotso 2000) since the sites have been revered historically and thus left undisturbed.

Radio-tracking work from western Sierra Leone has shown that White-necked Picathartes is able to utilise overgrown farmbush (Siaka 1998) and Salewski *et al.* (2000) noted their apparent ability to breed despite substantial disturbance near colony sites, though it is not known how successful this breeding event was. Thompson (1997) also demonstrated that the species can persist over long timescales (many decades) despite disturbance and our own observations show a high level of persistence over time. Although we found no significant difference in breeding activity between community forest and reserve colonies, despite a higher level of human disturbance in the former areas, it should be noted again that this study may have underestimated numbers of abandoned sites. Presently, more than 50% of active White-necked Picathartes colonies known in the Gola area are outside the forest reserve boundaries and seven of these were not used by the birds during at least one breeding season over the 2006–2010 study period (see discussion above). Five colonies in community forest had no recorded breeding activity in the final year of the study suggesting they may have been abandoned. However, two other colonies with no breeding activity in the first year of study were later active so a single inactive year is not necessarily indicative of abandonment. Thus, despite some tolerance of human activity, this species is affected by disturbance at its breeding sites, and therefore work with local communities to ensure active colonies in community forest remain undisturbed is a high priority for the regional population (Thompson *et al.* 2004). This will ensure that the population of White-necked Picathartes in the Gola Forest remains the largest in the country, spread across both protected and unprotected areas, which would be a model for other key sites in the region. The effective monitoring of these colonies in the years ahead will ensure that as community lands come under increasing pressure from agriculture any resulting impacts on the colonies will be quickly detected, providing opportunity to prevent their abandonment.

In summary, we suggest that the breeding population of White-necked Picathartes in and around the Gola Forest Reserve has remained stable in the last 20 years. Where colonies have been lost, this could be attributed to disturbance or habitat degradation, although we lack any specific measures of degradation. Modelling suggests that there may be many more breeding colonies waiting to be found, but these models could be improved with more records, and more environmental data.

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Appendix 1. Number of active nests recorded each year at White-necked Picathartes colonies surveyed over the 2006 to 2010 period (ND = no data). Site names and exact locations are kept confidential but protection status is given for each site (Protected = site located inside the Gola Forest Reserve boundary; Unprotected = site located in community forest, outside GFR boundary)

Site Code	Protection status	Active nests		
		2006–2007	2008–2009	2009–2010
1	Unprotected	1	ND	0
2	Protected	4	2	2
3	Protected	1	1	1
4	Protected	ND	ND	7
5	Protected	8	5	8
6	Protected	3	4	3
7	Protected	3	7	5
8	Unprotected	1	2	1
9	Unprotected	3	4	3
10	Unprotected	13	15	10
11	Unprotected	2	ND	3
12	Unprotected	0	ND	2
13	Unprotected	3	ND	ND
14	Unprotected	1	ND	1
15	Unprotected	1	ND	ND
16	Unprotected	3	3	2
17	Unprotected	1	1	1
18	Unprotected	2	3	0
19	Unprotected	0	ND	1
20	Unprotected	1	2	1
21	Protected	3	5	3
22	Protected	3	4	3
23	Unprotected	4	6	5
24	Protected	1	2	1
25	Protected	2	2	1
26	Protected	ND	ND	1
27	Protected	2	3	2
28	Protected	ND	2	ND
29	Protected	ND	1	ND
30	Protected	12	14	12
31	Protected	5	3	6
32	Unprotected	16	18	17
33	Unprotected	5	7	4
34	Unprotected	1	1	0
35	Unprotected	2	2	1
36	Unprotected	1	4	0
37	Unprotected	1	0	0
38	Protected	ND	ND	2
39	Protected	ND	ND	1
40	Protected	ND	2	2
TOTAL NO. OF SITES		**33**	**29**	**36**
TOTAL NO. OF ACTIVE NESTS		**109**	**125**	**112**