

Avian Nest-Site Selection Under Electromagnetic Stress: Evidence From Semi-Urban Ecosystems

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Abstract

Urbanizing landscapes increasingly expose wildlife to electromagnetic fields (EMFs) generated by telecommunication infrastructure, yet their ecological implications remain poorly understood. We investigated whether EMF exposure influences avian nest-site selection in three semi-urban ecosystems differing in land-use composition. Habitat utilization was first assessed relative to availability, followed by Bayesian logistic regression to evaluate the combined effects of landscape structure and EMF intensity across four frequency bands (900, 1800, 2100, and 2400 MHz). Birds did not select nesting habitats in proportion to their availability, indicating that habitat abundance alone does not determine nest placement. Instead, nest-site selection was associated with specific EMF variables and landscape features, with the influential EMF bands varying among sites. Negative relationships with nest occurrence were observed for EMF_900 and EMF_2400 in one landscape, and for EMF_1800 in another, while in the third area EMF_900 showed a negative association and EMF_1800 a positive one. These patterns likely reflect differences in local exposure thresholds and species-specific sensitivities within the breeding community. Our findings provide empirical evidence that existing EMF levels can shape avian nesting patterns in human-modified environments. Recognizing EMF exposure as an ecological factor is essential for urban planning and for managing biodiversity conservation in increasingly networked landscapes.

Keywords: Electromagnetic Fields (EMF), Nest-Site Selection, Mobile Phone Towers, Urban and Semi-Urban Ecosystems, Habitat Use and Availability, Bayesian Logistic Regression

1. Introduction

Nesting is a fundamental component of the breeding biology of birds and involves a series of complex processes. These include nest-site selection, nest construction, and incubation, each directed toward maximizing reproductive success, which is generally measured by the number of hatchlings that successfully emerge and become capable of independent survival. Each element of the breeding cycle holds particular significance and is influenced by a variety of factors. Birds tend to be highly selective when choosing nest sites due to one or several natural or human-induced factors,

such as inter- and intra-specific competition, nest predation, vegetation cover, light availability, habitat conditions, disturbance, and pollution [1-4].

During the past decade, electromagnetic pollution (“electrosmog”) has been suggested to influence nest-site selection and breeding success in some bird species [5]. For instance, Great Tits (*Parus major*) have been reported to significantly avoid areas with elevated EMF levels near radar installations [6]. Considering these potential effects of electrosmog on avian breeding ecology, similar

influences may be expected in other environments characterized by high EMF exposure. Based on this assumption, one of the objectives of the present study is to address the question:

Do existing EMF levels affect avian nest-site selection?

To examine this, the following hypotheses were formulated:

H₀: EMF levels do not affect avian nest-site selection.

H₁: EMF levels affect avian nest-site selection.

2. Materials and Methods

2.1. Nest Data

Preliminary information on nesting seasons was obtained from Marshall [7]. Each ISA was divided into 250 m × 250 m grids, and nest searches were conducted using a stratified nest monitoring protocol between April 2017 and May 2018 [4,8]. Ground-nesting birds were excluded due to time and manpower constraints. For each nest found, GPS coordinates were recorded; for baya (*Ploceus philippinus*), a colonial species, each colony was treated as a single nest. EMF values for all nest sites were extracted from the EMF maps generated in Mazumder [9]. The number of nests located were 45 for ISA1, 46 for ISA2, and 50 for ISA3.

2.2. Habitat Utilization Versus Availability

Before analyzing EMF effects, habitat use for nesting was assessed in each ISA. Habitat availability refers to the area accessible for nesting, while habitat use represents the portion actually selected. Habitat selection occurs when birds choose among available resources, and preference reflects the proportion of use when availability is equal. Birds commonly prefer certain habitats for nesting (Burger & Gochfeld, 2019) [10,11]. Quantification of such use is often expressed as the ratio of percentage use to percentage availability, with several indices available to assess habitat preference [12-15].

For this study, the following hypotheses were tested:

H₀: Habitats are not used for nesting in relation to their availability.

H₁: Habitats are used for nesting in relation to their availability.

Ivlev's Electivity Index (E_i) was used, calculated as:

$$E_i = \frac{u_i - a_i}{u_i + a_i}$$

where

u_i = proportion of nests in habitat i (habitat used),

a_i = proportion of habitat i available in the study area.

2.3. Occupied Versus Random Points (Revised)

Nest-site selection is influenced by multiple interacting factors, and therefore the effect of EMF alone cannot be examined in isolation. It is necessary to quantify the contribution of each factor to understand their relative influence. Synergistic interactions among environmental stressors may produce ecological outcomes that are not predictable from single-factor evaluations [16,17]. For

this reason, considering landscape structure without incorporating anthropogenic influences provides an incomplete basis for conservation assessments [18].

To evaluate the combined influence of habitat and EMF variables, we used the occupied versus random points approach [15,19-21]. Nest-site locations were treated as occupied points (regardless of the number of nests per point), and random points were generated in ArcGIS 10.3. Although selecting random points has some flexibility, they were distributed to ensure adequate representation of each ISA [15,19]. The same set of variables was extracted for both occupied and random points, following established approaches [3,11,19,21].

A total of nine predictor variables were considered: *five landscape parameters and electric field strength (E, V/m) from four EMF bands*. Landscape variables included *distance to water body, distance to road, distance to human settlement (all in meters), and easting and northing coordinates*. Distances were derived from LULC maps, while the values for easting and northing were obtained from ASTER SRTM imagery (USGS Earth Explorer) [9]. Electric field values for each point were extracted from EMF maps generated for each ISA [9]. The random points were 46 for ISA1, 46 for ISA2, and 51 for ISA3.

3. Statistical Analysis

3.1. Habitat Utilization Versus Availability

Areas of each habitat type were extracted from LULC maps for the three ISAs [9]. Nest locations were overlaid on these maps, and the number of nests in each habitat type was recorded. Expected habitat use (E_i) was calculated in MS Excel based on nest abundance and proportional habitat area (Table 1).

3.2. Occupied Versus Random Points

To examine factors influencing nest presence, nine environmental variables were compiled for both occupied (1) and random (0) locations within each ISA. The resulting data sets consisted of 10 columns (one binary response and nine predictors) and varied in row number (SA1: 91; SA2: 92; SA3: 101).

3.3. Multicollinearity Diagnostics

Prior to model fitting, explanatory variables were assessed for multicollinearity, as correlated predictors can bias regression estimates [22,23]. Variance Inflation Factors (VIFs) were calculated in R following Montgomery et al. (2012) and Zuur et al., and variables exceeding commonly accepted thresholds were excluded [24].

3.4. Bayesian Regression Modelling

Nest presence was modeled using Bayesian logistic regression implemented in the brms package (Bürkner, 2017) in R. The Bayesian framework integrates prior information with observed data to estimate posterior parameter distributions, providing robust inference for generalized linear models [25].

3.5. Model Selection and Marginal Effects

A full model (brm1) including all covariates was first fitted. Based on credible interval estimates, a reduced model (brm2) was then constructed, retaining significant predictors and all EMF variables due to their relevance to the study's central question. Model performance was compared using Leave-One-Out Cross-Validation (LOO-CV), with lower LOO values indicating stronger model support. Marginal effects were calculated to aid

interpretation of predictor influence on nest-site selection [26,27].

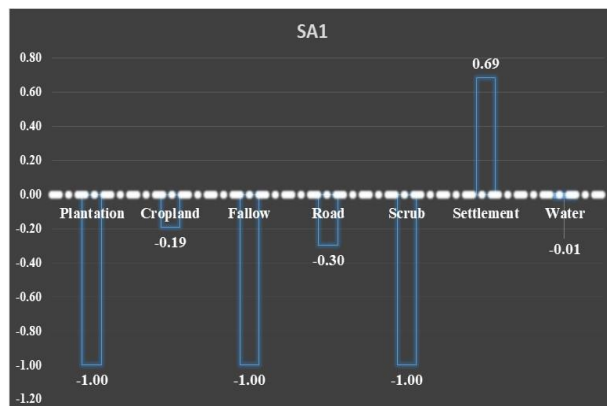
4. Results

4.1. Utilization Versus Availability

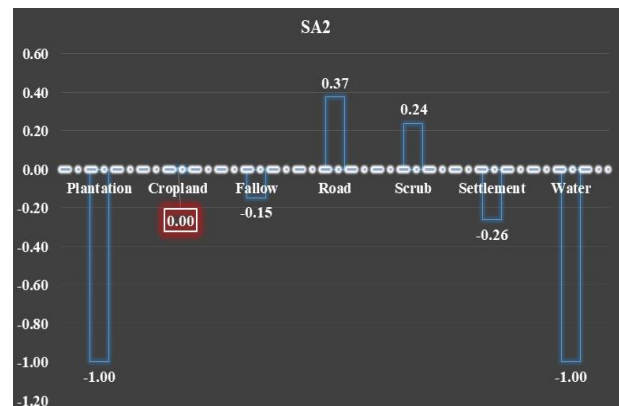
The values of E_i are provided in Table 2, with a graphical representation in Figure 1. These results indicate that birds do not use habitats in proportion to their availability.

Land use Class	SA1			SA2			SA3		
	Area (km ²)	% Area	No. of Nests	Area (km ²)	% Area	No. of Nests	Area (km ²)	% Area	No. of Nests
Cropland	4.73	75.7	22	3.83	61.3	28	5.00	80.0	41
Fallow	0.18	2.9	0	0.74	11.8	4	0.37	6.0	4
Plantation	0.20	3.3	0	0.10	1.6	0	0.02	0.2	0
Road	0.27	4.3	1	0.17	2.7	3	0.08	1.4	1
Scrub	0.05	0.7	0	0.67	10.7	8	0.47	7.5	1
Settlement	0.52	8.3	19	0.68	10.9	3	0.29	4.6	1
Water	0.30	4.8	2	0.06	1.0	0	0.02	0.3	2
Total	6.25	100	45	6.25	100	46	6.25	100	50

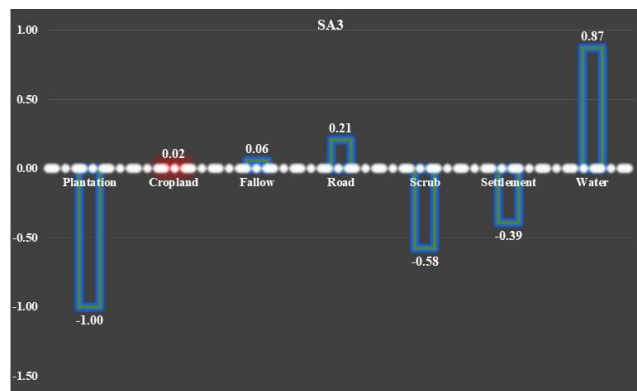
Table 1: Proportion of Land-Use Classes and Number of Nests in Each Class Across the Three ISAs



(a)



(b)



(c)

Figure 1: Graphical Representation of Ivlev's Index Across the Three ISAs

Ivlev's Index			
Habitat	SA1	SA2	SA3
Plantation	-1.00	-1.00	-1.00
Cropland	-0.19	0.00	0.02
Fallow	-1.00	-0.15	0.06
Road	-0.30	0.37	0.21
Scrub	-1.00	0.24	-0.58
Settlement	0.69	-0.26	-0.39
Water	-0.01	-1.00	0.87

Note: -1 = complete avoidance; 0 = no active selection; +1 = complete preference.

Table 2: Ivlev's Index Indicating Habitat use for Nesting Across the Three ISAs

Cropland, although the most available habitat, was not actively selected for nesting in any ISA, while plantations were consistently avoided. The E_i values for other habitats likewise indicate no clear preference relative to availability. Therefore, H_0 (habitats are not used in relation to their availability) is accepted. These results guided further evaluation of nest-site selection using the occupied versus random points approach.

4.2. Occupied Versus Random Points

➤ Multicollinearity Diagnostics

Variance Inflation Factors (VIFs) for all covariates are shown in Table 3. All VIF values fall within acceptable limits (Montgomery et al., 2012), indicating no multicollinearity concerns.

Variables	Intensive Study Area			
	SA1	SA2	SA3	SA_123
Distance to Water	1.08	1.42	1.39	1.16
Distance from human habitation	1.36	1.15	2.22	1.19
Distance from road	1.17	1.18	1.62	1.11
EMF_900	3.61	4.44	1.98	2.30
EMF_1800	3.71	4.76	1.47	2.50
EMF_2100	2.08	3.97	1.21	1.57
EMF_2400	1.76	3.17	1.21	1.54
Easting	1.09	1.12	1.08	1.03
Northing	1.22	1.09	1.08	1.03

Table 3: Variance Inflation Factors (VIFs) of Explanatory Variables

➤ Bayesian Regression Modelling

A) ISA1

Model summaries for brm1 and brm2 are presented in Table 4 (a and b), with model comparison in Table 4 (c). In brm1, distance

from human habitation and EMF_900 show negative relationships with nest-site selection; in brm2, EMF_2400 is also negatively related. Lower looic values indicate brm2 performs better and hence, H_0 is rejected, supporting H_1 for ISA1. Figure 2 (a-f) shows marginal effects.

ISA1 brm1					
	Estimate	Est. Error	l-95% CI	u-95% CI	Rhat
Intercept	1.347	0.974	-0.489	3.296	1
Dist to water	0.000	0.002	-0.004	0.004	1
Dist to human habitation	-0.007	0.002	-0.011	-0.004	1
Distance from road	0.000	0.001	-0.003	0.002	0.999
EMF_900	-14.638	7.626	-30.341	-0.548	1

EMF_1800	-0.144	9.018	-17.569	17.742	1
EMF_2100	16.169	6.283	4.662	29.518	1
EMF_2400	-23.464	15.479	-59.548	1.029	1
Easting	1.236	0.484	0.348	2.219	1
Northing	-0.843	0.476	-1.836	0.077	1

(a)

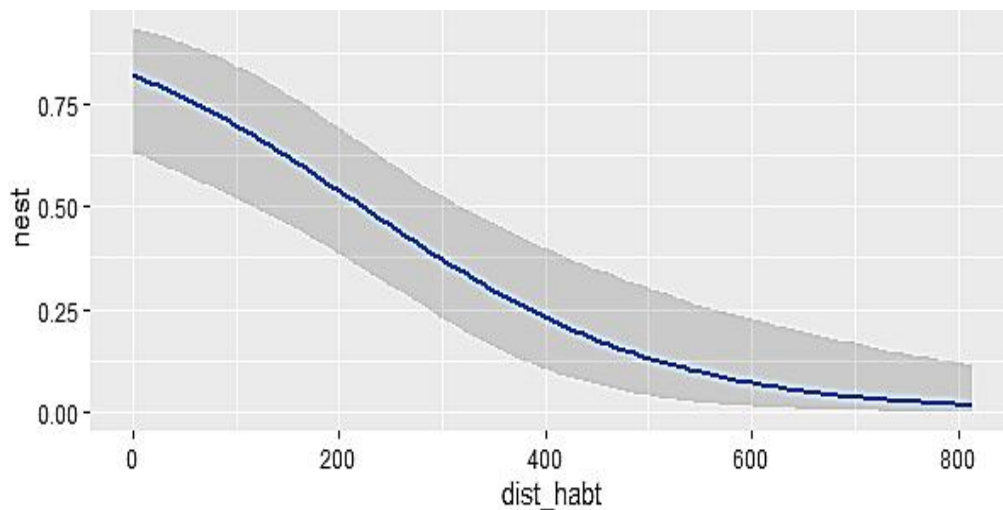
ISA1 brm2					
	Estimate	Est. Error	l-95% CI	u-95% CI	Rhat
Intercept	1.123	0.792	-0.388	2.712	1
Dist to human habitation	-0.006	0.002	-0.009	-0.003	1
EMF 900	-12.443	6.783	-26.93	-0.209	1
EMF 1800	-1.728	8.132	-17.302	14.713	1
EMF 2100	17.163	6.17	5.746	29.812	1
EMF 2400	-28.271	14.991	-63.485	-3.745	1
Easting	1.161	0.447	0.32	2.094	1

(b)

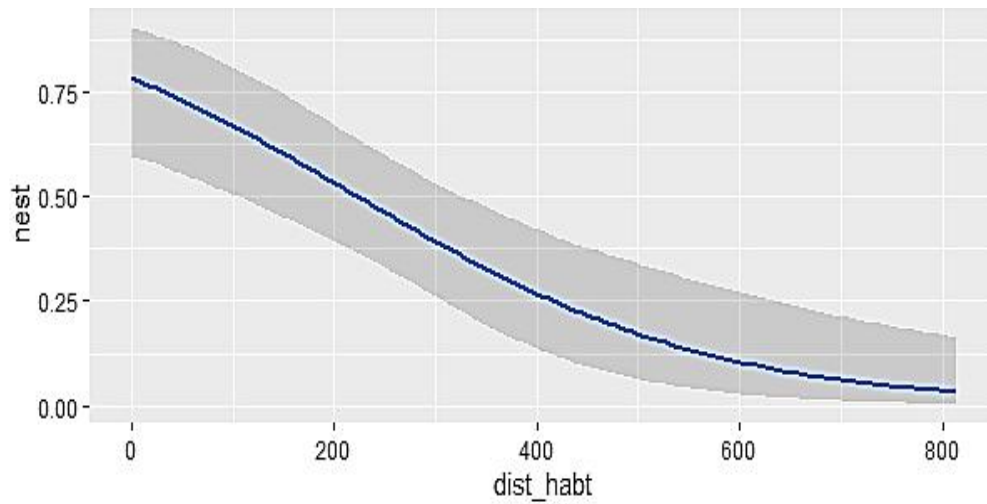
	brm1		brm2	
	Estimate	SE	Estimate	SE
elpd_loo	-54.8	8.3	-49.9	6.7
p_loo	15.1	3.6	8.8	1.8
looic	109.5	16.5	99.8	13.4

(c)

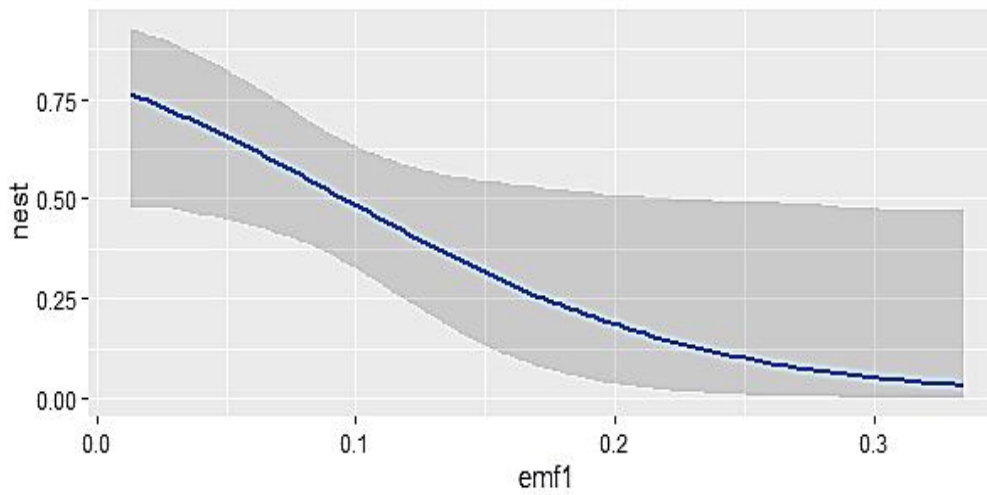
Table 4: (A & B): Model Summary of brm1 and brm2 for ISA1; (c) Model Comparison Using LOO-CV Method



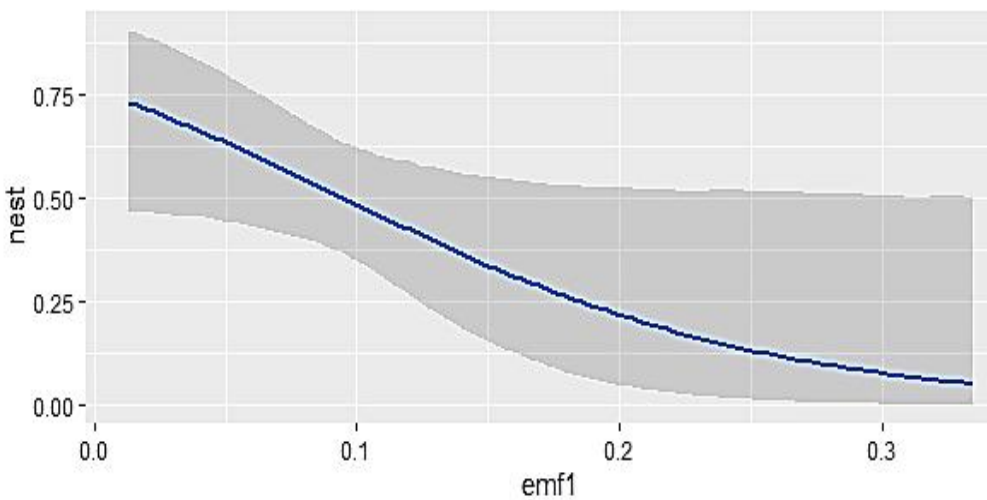
(a): Marginal Effects for distance from human habitation in brm1 for ISA1



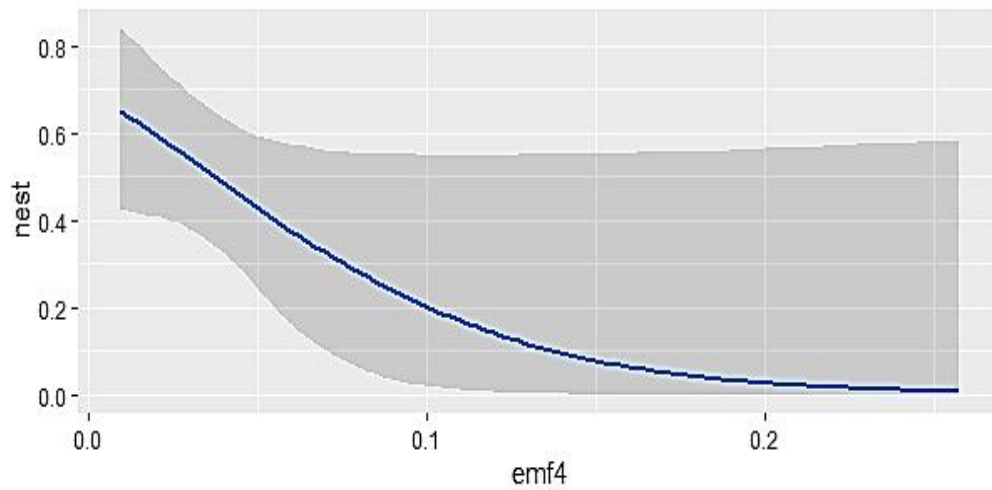
(b): Marginal Effects for distance from human habitation in brm2 for ISA1



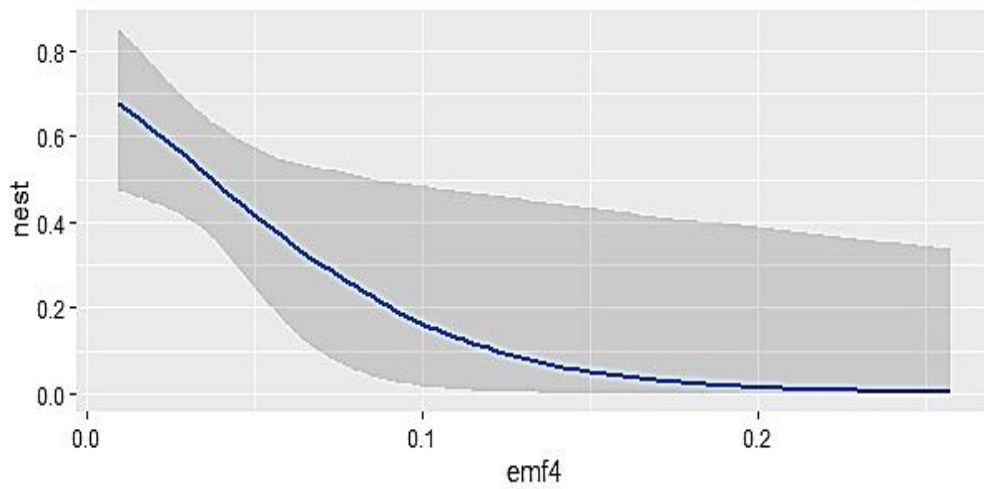
(c): Marginal Effects for EMF_900 in brm1 for ISA1



(d): Marginal Effects for EMF_900 in brm2 for ISA1



(e): Marginal Effects for EMF_2400 in brm1 for ISA1



(f) Marginal Effects for EMF_2400 in brm2 for ISA1

Figure 2 (A-F): Marginal Effects for Distance from Human Habitation, EMF_900 and EMF_2400 in brm1 and brm2 for ISA1

B) ISA2

Model summaries for ISA2 are shown in Table 5 (a and b), with comparison in Table 5 (c). In both models, distance from road and

EMF_1800 negatively influence nest-site selection. Lower looic values indicate brm2 is the preferred model and thus, H_0 is rejected, supporting H_1 for ISA2. Figure 3 (a-d) illustrates marginal effects.

ISA2 brm1					
	Estimate	Est. Error	l-95% CI	u-95% CI	Rhat
Intercept	0.356	0.684	-1.001	1.701	1
Distance from water	0.001	0.001	-0.001	0.003	1
Distance from road	-0.008	0.003	-0.015	-0.002	1
Distance to human habitation	-0.001	0.002	-0.004	0.003	1
EMF 900	10.642	5.644	-0.083	22.115	1
EMF 1800	-15.48	5.975	-27.874	-4.247	1
EMF 2100	-3.771	5.658	-15.457	6.801	1

EMF 2400	11.413	7.227	-1.827	26.1	1
Easting	0.103	0.35	-0.588	0.775	1
Northing	-0.291	0.353	-0.984	0.396	1

(a)

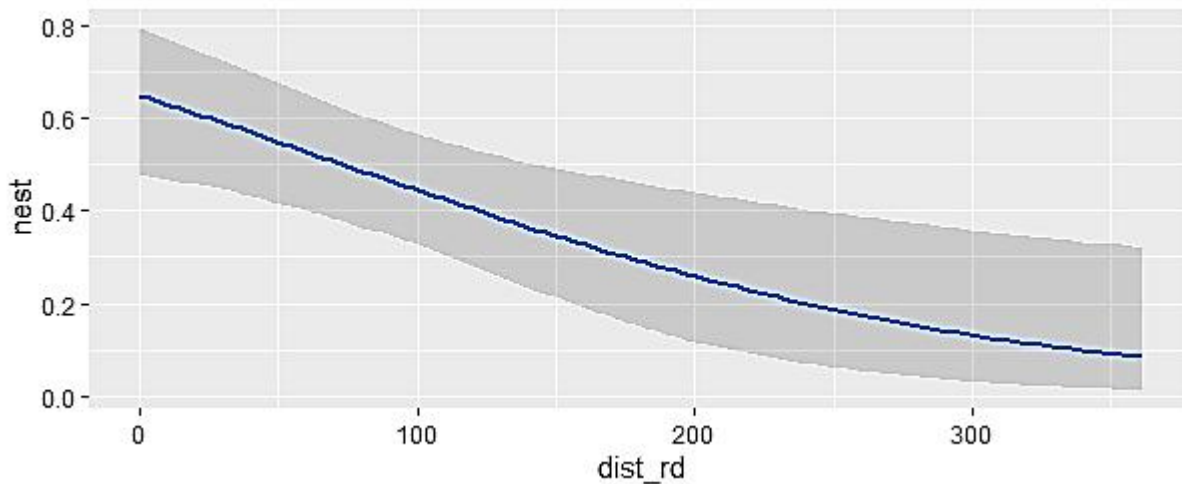
ISA2 brm2					
	Estimate	Est. Error	l-95% CI	u-95% CI	Rhat
Intercept	0.542	0.51	-0.478	1.522	1
Dist from road	-0.007	0.003	-0.013	-0.002	1
EMF 900	8.665	5.096	-0.843	18.866	1
EMF 1800	-14.024	5.475	-25.148	-3.765	1
EMF 2100	-4.471	5.677	-15.712	6.189	1
EMF 2400	12.844	7.114	-0.626	27.47	1

(b)

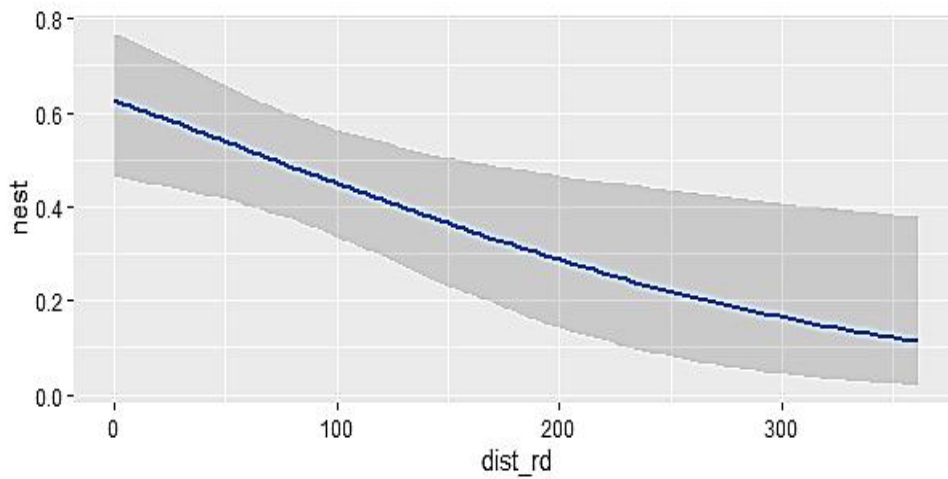
	brm1		brm2	
	Estimate	SE	Estimate	SE
elpd_loo	-69.7	5.1	-65.4	4.5
p_loo	12.6	1.6	7.1	1.2
loaic	139.3	10.2	130.8	9

(c)

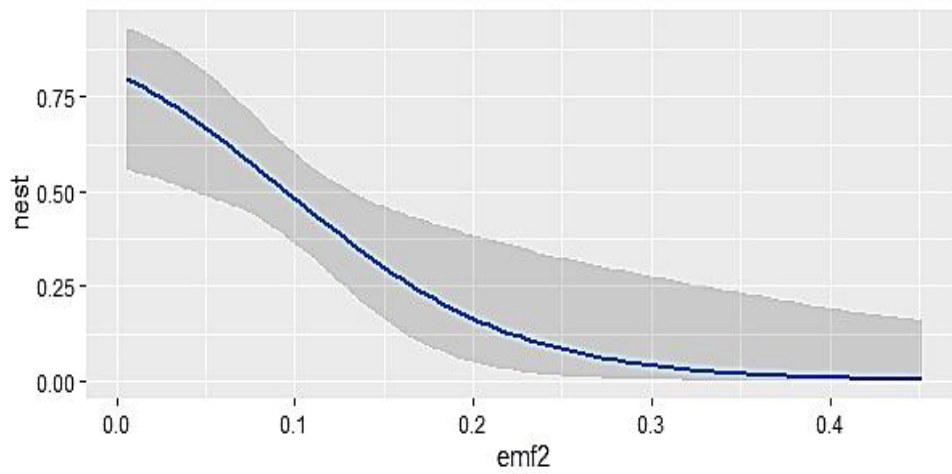
Table 5: (A & B): Model Summary of brm1 and brm2 for ISA2; (c) Model Comparison Using LOO-CV Method



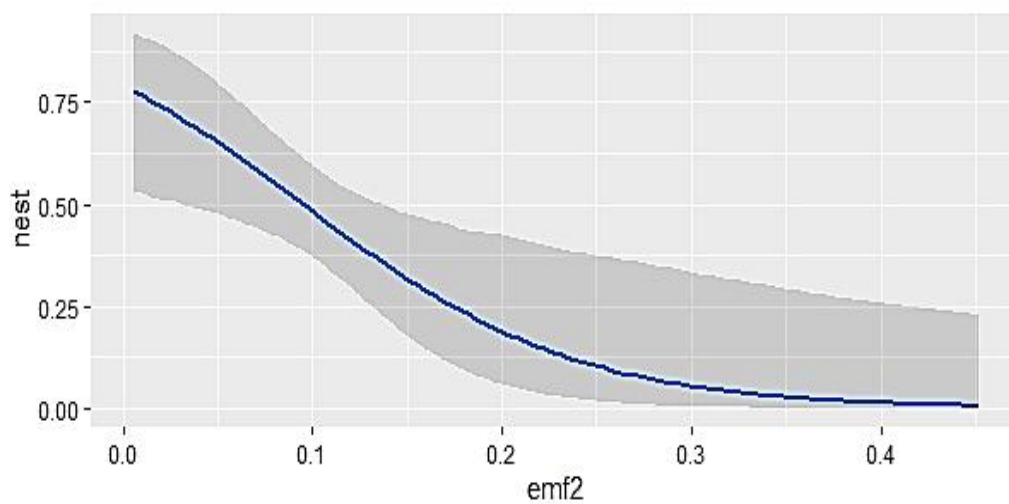
(a): Marginal Effects for Distance from Road in brm1 for ISA2



(b): Marginal Effects for Distance from Road in brm2 for ISA2



(c): Marginal Effects for EMF_1800 in brm1 for ISA2



(d): Marginal Effects for EMF_1800 in brm2 for ISA2

Figure 3 (A-D): Marginal Effects for Distance from Road and EMF_1800 in brm1 and brm2 for ISA2

C) ISA3

Model summaries for ISA3 are shown in Table 6 (a and b), with comparison in Table 6 (c). In brm2, EMF_900 shows a negative effect while EMF_1800 shows a positive effect on nest-site

selection. Lower looic confirms brm2 as superior and thus, H_0 is rejected, supporting H_1 for ISA3. Figure 4 (a–b) presents marginal effects.

ISA3 brm1					
	Estimate	Est. Error	l-95% CI	u-95% CI	Rhat
Intercept	-2.6	1.304	-5.199	-0.148	1
Distance from water	-0.002	0.001	-0.004	0	1
Distance to human habitation	0.002	0.001	-0.001	0.004	1
Distance from road	-0.001	0.001	-0.004	0.002	1
EMF 900	-9.247	5.36	-20.305	0.898	1
EMF 1800	20.184	7.99	5.164	36.228	1
EMF 2100	6.759	4.016	-0.901	15.187	1
EMF 2400	4.354	7.077	-9.253	18.01	1
Easting	0.694	0.328	0.066	1.347	1
Northing	0.304	0.34	-0.347	0.982	1

(a)

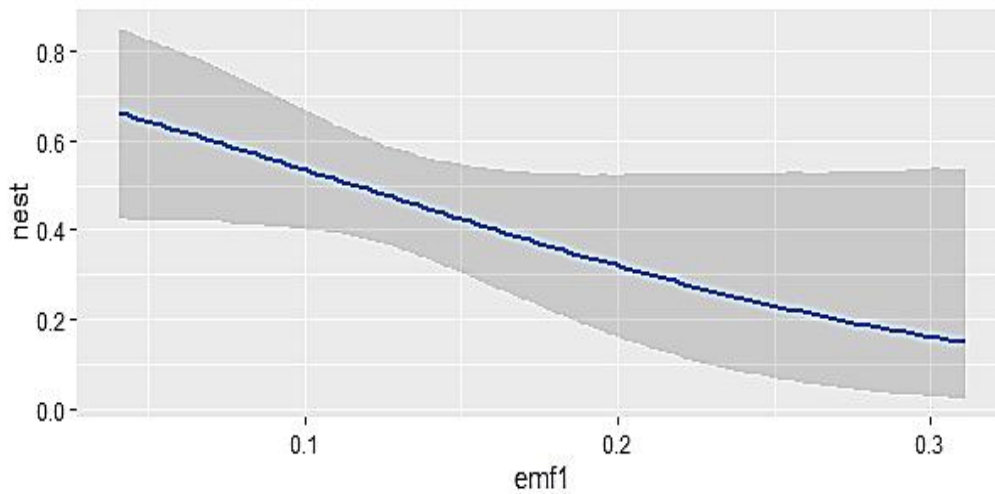
ISA3 brm2					
	Estimate	Est. Error	l-95% CI	u-95% CI	Rhat
Intercept	-2.293	1.073	-4.405	-0.226	1
EMF 900	-12.131	4.365	-20.932	-3.886	1
EMF 1800	21.727	7.789	6.922	37.882	1
EMF 2100	6.775	3.724	-0.193	14.123	1
EMF 2400	3.879	6.461	-9.164	16.776	1
Easting	0.567	0.322	-0.052	1.208	1

(b)

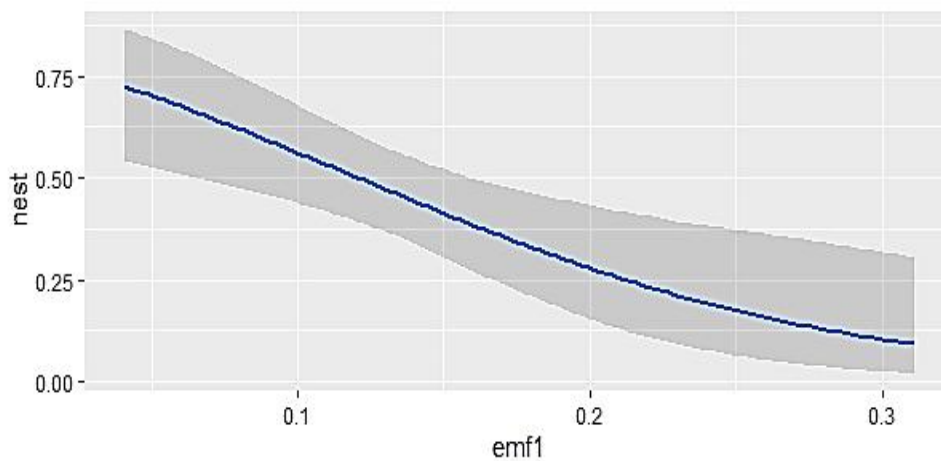
	brm1		brm2	
	Estimate	SE	Estimate	SE
elpd_loo	-74.9	6.1	-71.6	5.5
p_loo	12.7	1.6	7.6	1.2
looic	149.8	12.2	143.2	10.9

(c)

Table 6: (A & B): Model Summary of brm1 and brm2 for ISA3; (c) Model Comparison using LOO-CV Method.



(a): Marginal Effects for EMF_900 in brm1 for ISA3



(b): Marginal Effects for EMF_900 in brm2 for ISA3

Figure 4: (A & B): Marginal Effects for EMF_900 in brm1 and brm2 for ISA3

5. Discussion

Examination of the posterior estimates provides insight into the relative influence of the environmental covariates on nest-site selection. In ISA1, although distance from human habitation showed a negative association with nest-site occurrence, its effect was weaker than that of EMF_900, which in turn was weaker than the negative effect observed for EMF_2400. A positive association was observed for EMF_2100; however, this does not imply that EMF_2100 is beneficial for nesting. Rather, this pattern may reflect the spatial configuration of EMF intensity and the availability of remaining suitable nesting space within electromagnetic gradients.

In ISA2, distance from road exhibited a negative effect on nest-site selection, but this effect was smaller than that of EMF_1800, which again suggests that EMF exposure is playing a stronger role in site selection than local disturbance or proximity variables. In ISA3, EMF_900 displayed a negative association with nest-

site selection, while EMF_1800 appeared to have a positive association. It is unlikely that one frequency band is inherently harmful while another is beneficial. Instead, these patterns likely reflect *differences in spatial exposure levels and threshold responses*, where nest-site selection is shaped by locally varying radiation intensities.

Overall, the findings indicate that existing EMF levels influence nest-site selection across all three ISAs. Variation among sites in the frequency bands associated with nest-site selection may arise from (1) differences in exposure levels that exceed tolerance thresholds, and/or (2) species-specific sensitivities. As this study was conducted at the community level, it remains unclear which species are most affected by a particular EMF band.

Of the 141 nests recorded, only 83 could be confidently assigned to species. Several species had low nest numbers (e.g., *Falco jugger*,

Euodice malabarica), while others were more common, such as *Gracupica contra* (17 nests), *Corvus splendens* (31 nests), and *Ploceus philippinus* (20 colonies). Due to uneven sample sizes, interspecific comparison was not feasible. Consequently, species-level sensitivity to EMF could not be determined.

The present results demonstrate that EMF exposure plays a role in shaping nest-site selection in avian communities within the study region. These findings highlight the need for species-specific research to determine sensitivity thresholds and to identify taxa that may be at higher risk. From a conservation perspective, such research is essential to anticipate and mitigate potential ecological consequences, including long-term declines or local extirpation of sensitive bird species in human-modified environments.

6. Conclusion

The present study demonstrates that avian nest-site selection was not determined by habitat availability in any of the three ISAs. Instead, specific environmental and electromagnetic factors influenced site selection patterns. In ISA1, distance from human habitation, EMF_900, and EMF_2400 showed negative relationships with nest-site occurrence. In ISA2, distance from road and EMF_1800 had negative effects, while in ISA3, EMF_900 showed a negative association and EMF_1800 a positive association with nest-site selection.

These results indicate that existing EMF levels exert a measurable influence on nest-site selection across the study landscapes. The variation in the EMF bands associated with nest-site selection among ISAs may reflect differences in (1) threshold levels beyond which radiation exerts negative effects, and/or (2) species-specific sensitivities to particular frequency bands. Because this study examined a community of nesting species rather than individual species responses, it was not possible to identify which species are most sensitive to specific EMF levels.

Overall, the study suggests that EMF exposure may act as an ecological factor influencing avian breeding habitat selection. Future research that focuses on species-level responses and exposure thresholds will be essential for understanding vulnerability and for informing conservation planning in human-modified environments. The study also demonstrates the effectiveness of EMF mapping as a tool for landscape level assessment of EMF on avian nest-site selection. It is assumed that the approach and tools of the present study will go a long way in guiding future studies on this aspect of EMF-ecology.

For the present study, we adopted a multivariate approach keeping in mind the synergistic effects of some key contributing factors on the avian nest-site selection. We started with some key habitat parameters along with the EMF variables and the results are able to significantly answer the pertinent question. The results also demonstrate the effectiveness of *EMF mapping* to assess the effects of EMF on nest-site selection by birds.

The present investigation also has its own limitations as it fails to clearly explain as to which species avoid high EMF areas for nest-site selection and those which remain unaffected. This is again due to the fact that the study involves a community of nesting species and not just one or two species. The results of the present study, however, are expected to encourage more studies on this front, wherein target species are considered based on their conservation status and current population trend. We feel that decision-makers should consider similar studies on a priority basis and initiatives should be taken for the same. Also, the present study forms a sound basis for the adoption of EMF mapping for the purpose, since the findings of the present study are evidences strong enough to explain the effectiveness of the mapping approach as well as the effects of artificial EMF on avian nesting behaviour.

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Declaration of Generative AI and AI-Assisted Technologies

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