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Ornamental tree species drive the selection of nesting colony sites by Black-crowned Night Herons (*Nycticorax nycticorax*) in an urban habitat

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EXECUTIVE SUMMARY

Human-wildlife conflict in downtown Oakland, California, has intensified due to Black-crowned Night Herons nesting in urban areas, leading to sanitation concerns, risks to bird safety, and disrupted community spaces. Previous efforts to relocate herons have had limited success, highlighting the need for a better understanding of their nesting preferences. Here, we investigated the habitat preferences of Black-crowned Night Herons (*Nycticorax nycticorax*) in an urban habitat, while focusing on nesting site selection relative to tree species and ambient environmental factors. We had three primary objectives: (1) examine the influence of tree characteristics (species, canopy cover, height, trunk diameter) on heron nest site selection; (2) the impact of disturbances on herons from predators and human activities; and (3) the role of food availability, in the form of human-generated trash and litter. Surveys spanned from 2015 to 2024, integrating both historical records and contemporary field surveys. Historical data were based on archival observations of nesting sites and environmental conditions, whereas contemporary data were obtained through direct field measurements of tree characteristics, site disturbances, and proximity to food resources. Nest site selection favored non-native tree species, particularly Chinese banyan (*Ficus microcarpa*) and Brazilian peppertree (*Schinus terebinthifolius*), which provide dense, protective canopies. There was a significant positive relationship between canopy cover of these tree species and nesting probability, whereas canopy height negatively impacted nest site selection. Unexpectedly, the presence of human refuse near nesting sites was positively correlated with nest occupancy, suggesting the herons obtained an additional food resource. Furthermore, there was a positive trend between trunk diameter and canopy cover and a negative association with distance to a water source (e.g. lake). Overall, our findings highlight the adaptability of night herons to living in urban environments and underscores the importance of tree species composition and human activity as factors that can influence their nest site selection. The predictive map created has utility by urban forest managers for anticipating areas likely to be colonized by Black-crowned Night Herons in future years. This work has implications for urban planning such that targeted tree planting and management could mitigate human-wildlife conflicts and support conservation efforts.

INTRODUCTION

Urban birds face significant challenges due to the design of urban landscapes and human activities, compounded by the rapid growth of cities and habitat fragmentation and loss (Snep et al., 2016). Urban areas often lack contiguous green spaces and are dominated by non-native vegetation, which diminishes habitat quality for birds (Snep et al., 2016). Domestic animals such as cats pose major risks as predators, especially to fledglings. While modern infrastructure, including sealed buildings and mirrored windows, lead to high mortality rates from collisions and deprive birds of nesting opportunities (Snep et al., 2016). Urban environments further complicate these challenges by introducing varied interactions between birds and humans. For example, birds in urban areas exhibit behavioral plasticity, responding differently to human presence compared to native predators (Weaver et al., 2018). This behavioral variation highlights the complex nature of human-wildlife conflicts in urban settings, as birds must navigate increased human encounters and potential threats from domestic and structural dangers (Weaver et al., 2018).

A notable example of these challenges can be observed in Oakland, California. Lake Merritt is a man-made tidal slough in the city limits and makes up a small portion of the larger tidal estuary of Laguna Peralta. Established as the nation's first wildlife refuge in 1869, five bird islands were created between 1925 to 1956. Hundreds of individual waterbirds, including egrets and Black-crowned Night Herons (hereafter herons or night herons) occupy these islands (Mullins, 2015).

In the late 1990s and early 2000s, several projects were initiated to enhance Lake Merritt's environmental quality and accessibility, particularly following the passage of Measure DD in 2002. These efforts included the removal of non-native plants and shrubs to restore the lake's natural habitat (Mullins, 2015; Lefebvre, 2020). Unfortunately, this removal disrupted the nesting habitats of waterbirds that inhabited these islands. This action likely contributed to the movement of night herons to new areas within Oakland city limits, including Wilma Chen Park (formally known as Madison Square Park) within the city's Chinatown neighborhood. In 2014, subsequent removal of trees along the border of Wilma Chen Park further displaced nesting night herons, forcing them to disperse into downtown Oakland.

The establishment of heron nesting colonies in this urban environment has led to significant human-wildlife conflict, negatively affecting both the birds and the local community.

The sidewalks and cars parked beneath these nesting trees get covered in bird droppings, raising sanitation concerns and potentially reducing foot traffic for nearby businesses. Additionally, concrete sidewalks and lack of understory pose a danger to chicks, who spend part of their development on the ground (Lefebvre, 2020). Falls from trees can result in serious injuries or expose chicks to traffic fatalities. Efforts to deter nesting through removal and/or trimming of trees have proven ineffective, as the herons simply relocate to nearby trees, perpetuating the problem.

Previous attempts to relocate heron nesting colonies have been successful in other cities. For example, in the 1990s a colony in Long Beach, California was successfully relocated from a closed naval station that was scheduled for demolition (Crouch et al., 2002). The relocation involved several strategies. Initially, the trees where birds nested, along with some breeding adults and chicks, were physically moved to a new site. To encourage the remaining birds to follow, decoys and recordings of vocalizations were used to attract them to the new location (Crouch et al., 2002). This comprehensive approach proved effective, resulting in an increase in successful hatchlings by the year 2000 (Crouch et al., 2002). In Oakland, following a successful campaign to designate the Black-crowned Night Heron as the city's official bird, efforts were launched to move them from their Chinatown nesting sites, back to Lake Merritt (Lefebvre, 2020). Despite these efforts, the relocation experienced significant setbacks. The remaining primary nesting trees in downtown were removed, leading to the death of several heron chicks and a sharp decline in active nests—from 156 in 2018 to 55 in 2019 (Lefebvre, 2020). The city ultimately decided to terminate the relocation project early, due to high costs and limited success of the measures, leaving many herons to continue nesting in downtown areas (Lefebvre, 2020). This situation underscores the ongoing challenges of managing urban wildlife and the complexities involved in effectively addressing human-wildlife conflicts.

In response to the continued human-wildlife conflict in Chinatown, downtown Oakland, and unsuccessful past relocation attempts, this current study aims to characterize the heron nesting trees in this dense urban environment. Our objective was to understand whether night herons choose specific trees (or character traits of trees) to nest, which can inform future relocation attempts and mitigate human-wildlife conflict.

Night herons have historically shown a preference for nesting in areas with significant vegetation that remains above the ground or water and does not die off seasonally (Fournier et

al., 2021). The birds tend to favor sturdy trees in woody areas, which can provide cover from predators, and average canopy cover is about 47%, with typically dense foliage (Kazantzidis et al., 2013). Night herons commonly nest in non-native eucalyptus trees, although they can be found in some oaks and shrubs (Kelly et al., 2007). Nests established later in the breeding season are generally less successful than those established earlier, possibly due to factors such as increased predation pressure or environmental conditions (Fournier et al., 2021). Common avian predators of night herons include the American Crow (*Corvus brachyrhynchos*), common Raven (*Corvus corax*), and western gulls (*Larus occidentalis*), while common mammalian predators include Racoons (*Procyon lotor*; Kelly et al., 2007; Hothem et al., 2004). Hunt (2016) examined the breeding success of a night heron colony in Lincoln Park, Chicago, IL, hypothesizing that changes in natural habitats or prey availability were driving the birds to seek new nesting locations. In this urban park, herons demonstrated behavioral flexibility when selecting nesting sites, choosing less protective canopies based on the size of the colony. Night herons were also likely to reuse nesting sites from previous years if they were successful (Hunt, 2016).

In the present study, we tested three non-exclusive hypotheses for what might influence nest site selection: (1) nest site selection is influenced by the characteristics of colony tree species, such as tree species, canopy closure, height, and trunk diameter, (2) disturbance from predators and/or humans negatively affects nest site selection, and (3) food availability, in the form of human-generated trash and litter, impacts nest site selection. We conducted intensive monitoring of night heron colonies and habitat conditions in Oakland's Chinatown neighborhood and compiled historical data collected via a community science monitoring program dating back through 2015 to identify drivers of colony nest site selection. We used these data to describe long-term night heron use of the landscape and to create a habitat suitability model that tested our hypotheses to inform tree management.

METHODS

Species Life History

The Black-crowned Night Heron (hereafter night heron) is a sturdy and stocky bird, recognizable by its distinctive black crown and back in adults, while juveniles are marked by spotted brown and white plumage (Sibley, 2016). This heron is widely distributed, with populations across North America and Western Canada (Sibley, 2016). In California, night herons are commonly found in lowland and foothill areas, particularly around the Salton Sea, Colorado River, and the

San Francisco Bay Area. They are especially known for their large nesting colonies (Audubon Society).

Night herons thrive in various aquatic habitats, including marshes, ponds, and tidal flats. Although they primarily forage at night (Sibley, 2016), they are also active during daylight hours (Audubon Society). Their breeding period extends from early March to late July, during which they build nests in dense foliage or in wetland areas. These nests are typically located in groves, on islands, or above water (Granholm). The herons' diet mainly consists of fish but also includes crustaceans, amphibians, and small mammals (Granholm).

Historical and Geospatial Data

We compiled historic field data from 2015-2020, collected via volunteers through San Francisco Bay Bird Observatory (SFBBO), using a variant of the protocol previously described (https://colonialwaterbirdprogram.weebly.com/protocol.html). These data were collected on various nest visibility and tree habitat characteristics, concomitant with observations of breeding counts and colony disturbance events.

Contemporary Field Data Collection (March-August 2024)

During the 2024 breeding season (March-August), field data were collected following a modified protocol for monitoring waterbird colonies (described fully at https://colonialwaterbirdprogram.weebly.com/protocol.html). Briefly, at each visit, biologists and trained community science volunteers tallied breeding counts for each colony tree, including the number of breeding adults, young, and nests at each stage of development. Nest stages ranged from pre-nesting activities (Stage 0), egg incubation (Stage 1), down and partially feathered chick development (Stages 2–3), pre-fledgling onto nearby branches (Stage 4) and, eventually, fully fledged young (Stage 5). If a nest stage could not be determined due to poor visibility, it was recorded as unknown. Additionally, brood sizes at Stage 4 were counted as an estimate of the fledging rate, documenting the number of chicks per nest, with only active nests being included in the final counts. At each visit, nest visibility was classified as either good (G), moderate (M), or poor (P), with any limitations in visibility described in detail.

Nesting tree habitats were characterized by estimating tree height, the type of foliage present, and further categorized as bare branches (B), deciduous leaves (D), or evergreen needles (E). The availability of potential food items within twelve meters of heron nests were noted as whether there was no obvious food source (N), street litter (L), open garbage bins (G), or natural

prey items (F). Disturbance events were recorded by type, including avian disturbances (A), human activities such as tree trimming (HT), tree removal (HR), harassment (HH), weather-related disturbances (W), mammalian intrusions (M), observer presence (O), unknown predators (P), or other unknown sources (U). Observations of disturbance were also categorized as directly observed (O) or inferred from site conditions (I), with the proximity of the disturbance noted as occurring on the same tree (T) or nearby on the same city block (N). The result of the disturbance was recorded as no response (0), a behavioral response (1), nest failure (2), colony abandonment (3), or a pre-season disturbance before the birds' arrival (4).

Comprehensive Mapping of Habitat Characteristics

Canopy Closure Estimation: In addition to surveys at active colonies, we gathered habitat data on all trees within all city blocks encompassing the study area. A convex densiometer (Make and Model A) was used to estimate the percentage of the canopy that was closed. This was done by standing under the tree facing the road, holding the densiometer level and 12 inches away from the face, and counting the number of squares that the canopy covered. Each count was multiplied by 1.04 to calculate the percentage out of 100. Additionally, geospatial data from the Oakland Public Tree Map was utilized (City of Oakland Dept of. Public Works, 2020). This dataset included information about public trees in the study area, including their species, canopy height, canopy cover, and diameter at breast height (DBH). For a small subset of trees that were not within the database (e.g., private trees), canopy height, DBH, and tree species were estimated in the field or assigned the mean value from the dataset.

Further evaluation was made on the identified tree species to determine common characteristics that might influence the likelihood of night heron nesting. This involved reviewing botanical and ecological studies to identify attributes such as canopy structure, height, and cover that could make these tree species favorable for nesting.

Disturbance Event Data Collection

Disturbance events for each city block in the study area were collected using the methods previously described. This included disturbance data for trees not currently used by night herons as nesting sites. Data collected included survey type (H = habitat, B = night heron present but not nesting, C = colony on this block), tree IDs for all specimens on a given city block, as well as street name, and cross streets.

Data Analysis

All data analysis was performed using R (v 4.3.1). The primary objective was to explore the relationship between tree and habitat characteristics and night heron nesting through statistical modeling and visualization.

Data Preparation

The data, uploaded to R and visualized using the *dplyr* (v 1.1.4), *tidyr* (v 1.3.1), and *lubridate* (v 1.9.3) packages. Binary occupancy variables were created for survey and block disturbance data regarding food, disturbance types, and tree occupation. Data from multiple visits were merged by combining field survey data with GIS data, and a tree was marked as occupied if it had one or more nests. The resulting dataset included colony presence or absence, along with densiometer data, GIS data, survey data, and block disturbance data for each tree. For sites visited more than once per season, the *dplyr* package was then used to calculate the maximum occurrence of food and disturbance types (i.e., if food was ever present, it was listed as present).

Statistical Modeling

To investigate the factors influencing night heron nesting site occupancy, we employed a systematic approach involving model selection and averaging (base package *stats*). This was accomplished using the get.cov.combinations() function, which utilized the *data.table* (v 1.15.4) package for efficient handling of data tables. The combinations() function from the *gtools* (v 3.9.5) package was used to generate these combinations. Following this, we formulated a series of model equations by concatenating covariate names into base formulas using the get.modelset() function. This process resulted in a diverse set of models incorporating various combinations of covariates. Each model formula was then applied to the dataset through the run.modelset() function, which fit generalized linear models (GLMs) with a binomial family to the data using maximum likelihood estimation. To assess model performance, we calculated the Akaike Information Criterion corrected for small sample sizes (AICc). The process.output() function was used to compute AICc values for each model, identify the top models based on their AICc weights, and extract coefficients along with their confidence intervals. For models with AICc weights greater than 0.01, we performed model averaging to obtain robust estimates of covariate effects using the modavg() function. Covariates included modes of litter, garbage, and trash, presence of tree species (*Ficus microcarpa* and *Schinus terebinthifolius*)-the two species most commonly associated with nests during field data collection-, and various measures of canopy

cover and height. Some covariates were excluded from the analysis due to issues such as complete separation, insufficient observations of occupied trees, or high collinearity between variables.

Visualization

Figures were created using the *dplyr* and *ggplot2* (v 3. 5.1) packages to inspect the data, identify trends, and visualize outcomes. We created marginal effect plots to estimate how habitat variables related to the probability of selection of a nesting colony site. Predictive maps were also generated using *ggplot2* to illustrate the results.

We used basic summary statistics to explore whether observations in 2024 were consistent with historical use of habitats across longer time periods and to identify any common trends in habitat selection.

RESULTS

Tree Species

In the study area, a diverse range of tree species was identified, exhibiting considerable variation in height, canopy cover, and DBH. Night herons exhibited a substantial preference for Chinese banyan (*Ficus microcarpa*) and Brazilian peppertree (*Schinus terebinthifolius*), which collectively accounted for the majority of active nesting sites (50.0% and 40.4%, respectively). Other trees included a variety of non-native species such as *Tristaniopsis conferta*, *Cinnamomum camphora*, and *Podocarpus gracilior*, among others, each contributing uniquely to the habitat structure. The Prominence of *F. microcarpa* and *S. terebinthifolius* as preferred nesting sites likely reflects the structural attributes these species offer, which align with the herons' nesting requirements (additional details on tree and habitat characteristics are provided in Appendix One).

Linear Regression Models

We employed model selection based on Akaike's Information Criterion corrected for small sample sizes (AICc) to identify the best-fitting model for predicting night heron nesting site occupancy. The top model included canopy cover, canopy height, presence of *F. microcarpa* and *S. terebinthifolius*, and presence of trash (Table 1). This model was significantly stronger than competing models with a demonstrated strong support with a cumulative model weight of 42% (Table 1).

Field observations of current heron nest occupancy tend to increase with larger DBH, greater canopy cover, and shorter trees, reflecting similar trends found in the final model (Figure 3). Although DBH's effect was not strong enough to be retained in the top model, its observed positive association with occupancy suggests it may still play a role in habitat suitability.

Canopy cover had a significant positive effect on nest occupancy probability (*Z score* = 2.550, p = 0.012), indicating that sites with more extensive canopy cover are preferred by night herons. In contrast, canopy height shows a significant negative effect (*Z score* = -2.771, p = 0.006), suggesting that shorter canopies are favored for nesting. The presence of *F. microcarpa* trees had a notably strong positive effect on occupancy (*Z score* = 5.420, p < 0.001), reflecting their critical role in providing suitable nesting conditions. Similarly, the presence of *S. terebinthifolius* trees significantly enhances the likelihood of occupancy (*Z score* = 6.090, p < 0.001). The presence of trash near the nesting site also positively influences occupancy (*Z score* = 2.178, p = 0.030) (Table 2).

Marginal effects plots illustrate these relationships (Figures 4-7, left side): canopy cover is associated with increased occupancy probability, while canopy height corresponded with a decrease. The presence of *F. microcarpa* and *S. terebinthifolius* trees significantly raised the likelihood of site selection, whereas the presence of trash also moderately increased occupancy probability.

Single predictor variables also significantly associated with nesting herons (Figures 4-7, Right side). For example, canopy height (Figure 5) showed a clear negative relationship with occupancy, consistent with the model's coefficient estimates. There was a positive association between trash presence and nest occupancy where occupancy probability increased as trash levels increased (Figure 7). These visualizations provide a nuanced understanding of how individual factors influence nesting behavior.

Model-averaged results further support these findings, where *F. microcarpa* and *S. terebinthifolius* presence showed consistent positive effects across models (Table 3). Canopy height was negatively correlated with occupancy, suggesting a preference for shorter trees. Environmental characteristics provided additional context about nesting habitat use. For example, distance in km to the nearest large water source (km2water) showed a negative relationship to nest occupancy (Figure 8). The effect of DBH on occupancy was positive (Figure 9). This suggests that while DBH may not be a major factor, its role in habitat structure cannot be

discounted. Canopy cover within 100 meters (ccb 100m) also had a negative effect, suggesting a potential trend towards less preference for nearby canopy cover, though the effect was not strongly conclusive (Figure 10).

In order to identify likely hotspots of new colony formation to help inform management of the urban landscape, we mapped the model-averaged predictions for each tree for which habitat measurements were taken within the study area (Figure 11). Results suggest that most of the selected-for trees have already been colonized (diamonds), while most remaining uncolonized trees have low probability of selection (<0.1). However, our model suggests a strong likelihood of colonization of the western block of the Lake Merritt BART (bounded by 8th, 9th, Oak, and Madison St).

DISCUSSION

This present study explored the nesting habitat preferences of night herons in Chinatown, Downtown Oakland, CA, with a specific focus on their nesting site selection relative to tree species and environmental factors. We tested three non-exclusive hypotheses: (1) nest site selection is influenced by the characteristics of colony tree species, such as tree species, canopy closure, height, and trunk diameter, (2) disturbance from predators and/or humans negatively affects nest site selection, and (3) food availability, in the form of human-generated trash and litter, impacts nest site selection.

Our results highlight that night herons exhibit a preference for nesting sites with higher canopy cover and shorter trees, with a marked preference for non-native tree species such as Ficus and Pepper trees. Additionally, anthropogenic factors like trash play a notable role in site selection, possibly providing food resources. These findings underscore the species' adaptability to urban environments and emphasize the importance of tree species composition and human activity in influencing nesting site occupancy.

Tree species

The data revealed a distinct preference for night herons to nest *F. microcarpa* (Chinese banyan) and *S. terebinthifolius* (Brazilian peppertree), consistent with the herons' known affinity for trees that provide dense, protective canopies (Kelly et al., 2007). Both species are hardwood trees with spreading canopies, moderately strong branches, and multi-trunked structures. Their non-native status in California is explained by the lack of native trees in Chinatown, Downtown

Oakland. The high proportion of nests in these species suggests that their structural characteristics—such as canopy cover and height—are crucial for the birds' nesting success.

However, it is important to note that because of the strong influence of tree species on model results (Tables 1–3) may be misleading if the current close association between *F. microcarpa* and *S terebinthifolius* is due to philopatry (i.e., first-time breeders selecting trees for nest colonies that are similar to the tree species they were hatched in). If philopatry is partially responsible for observed patterns, once occupancy of suitable colony sites in these two species is fully saturated—which appears likely to occur soon based on current maps showing most highly suitable trees in these species have already been colonized (Figure 11)—it is possible that the birds will begin nesting in other nearby trees. Indeed, the decreased use of *F. microcarpa* trees (from 70.90% to 44.82%) and the increase in the use of *S. terebinthifolius* (from 18.18% to 34.48%) in the current breeding season, could be explained by the removal disturbances (i.e., tree trimming). At least four *F. microcarpa* previously used as nesting trees were trimmed prior to breeding in 2024, corresponding to colonization of new trees around the Lake Merritt BART region highlighted as a hotspot of new potential colonizations (Figure 11). If philopatry is partially responsible for the very strong selection for *F. microcarpa* and *S terebinthifolius*, there may be more plasticity in their colony tree selection than the current strong bias towards these two species suggests. Future monitoring in 2025, once planned tree removal around the Lake Merritt BART has occurred, may shed light on these question.

Tree characteristics

Our analysis revealed a positive trend between canopy cover and nesting probability, highlighting the importance of dense foliage for protection and reduced predation risk (Fournier et al., 2021; Kelly et al., 2007). This emphasizes the critical role of tree cover in providing suitable habitats for urban-nesting species (Reale et al., 2004). In contrast, canopy height exhibited a negative effect on nesting probability, indicating a preference for shorter trees. This negative association with canopy height suggests that taller trees may not offer optimal nesting conditions, possibly due to increased exposure to predators or environmental stressors, aligning with findings on species' adaptation to specific tree characteristics in urban habitats (Leveau, 2022).

Interestingly, the presence of trash near nesting sites was positively associated with nesting probability. While human disturbance is often associated with reduced nesting success,

consistent food resources in the form of trach may offset these impacts. This finding reflects behavioral flexibility observed in other urban studies, where birds exploit human-modified habitats to their advantage (Reale et al., 2004; Leveau, 2022).

The relationship between trunk diameter (DBH) and nesting probability shows a positive trend, with larger trunks linked to higher occupancy rates. This trend approached significance, indicating that while the effect of trunk diameter on nesting probability is weaker compared to other variables, it may still be an important factor. This highlights the structural stability larger trunks provide, a factor that has been noted as critical for urban nest site selection (Reale et al., 2004). However, the influence of DBH is less pronounced than other factors, suggesting that trunk size, while relevant, may not be as critical in determining nest site selection.

In contrast, both distance to water and mean canopy cover within 100 meters exhibit negative associations with nesting occupancy. As the distance to water increases, the likelihood of occupancy decreases, suggesting that proximity to water provides critical resources, such as natural food sources like fish, or reduces predation risk. Proximity to water has been emphasized as a key factor in other research (Reale et al., 2004). Similarly, mean canopy cover within 100 meters shows a negative association, indicating that higher canopy cover in the surrounding area is linked to lower occupancy rates. Possibly due to the scarcity of densely clustered trees in this urban environment, which might reduce the suitability of nesting sites. A challenge faced by urban-nesting species (Leveau, 2022).

These results resonate with prior studies emphasizing the complex interplay of ecological and anthropogenic factors shaping bird nesting behavior in urban environments. Moreover, the observed adaptability and resourcefulness in nest site selection align with findings on urban species' resilience to environmental pressures, reflecting the capacity of species like night herons to exploit urban resources effectively(Hunt, 2016; Reale et al., 2004; Leveau, 2022).

Management implications

The results from the current study offer several valuable insights for urban planning and wildlife management in Chinatown and the surrounding areas of Oakland, particularly with respect to the nesting preferences of night herons. Understanding the habitat preferences of night herons can give effective tree planting and management strategies to mitigate human-wildlife conflict and support the conservation of these birds.

Based on our results, the city of Oakland can make informed decisions about tree planting and management in the Chinatown district and around Lake Merritt. The characteristics of *F. microcarpa* and *S. terebinthifolius*—such as their dense, closed canopies and horizontal branching patterns—are particularly beneficial for night herons. Leveraging these attributes in alternative areas, like Lake Merritt, could help attract night herons away from more urbanized areas where their presence causes conflicts. For example, planting or preserving trees with similar canopy attributes around Lake Merritt could draw night herons to these areas, benefiting both the birds and the local community.

Conversely, incorporating tree species with different characteristics from those of *F. microcarpa* and *S. terebinthifolius* within the Chinatown district could reduce the likelihood of night heron nesting in these areas. This proactive approach in urban planning can help balance the needs of wildlife with those of human residents, fostering coexistence and minimizing disruptions.

Overall, the insights gained from the present study emphasize the importance of targeted tree planting and management strategies in urban environments to address human-wildlife conflicts and promote the conservation of avian species. Implementing these recommendations can contribute to more harmonious interactions between night heron and urban communities, ensuring both the ecological health of the area and the well-being of its residents.

CONCLUSIONS

This study aimed to enhance our understanding of night heron nesting preferences in Chinatown, Downtown Oakland, by examining the influence of tree species and environmental factors. The findings reveal that *F. microcarpa* and *S. terebinthifolius* are preferred nesting sites for night herons, highlighting the significance of canopy characteristics in their site selection. While the study confirmed the importance of canopy, distance to water and DBH do not show the same strong relationship with occupancy, suggesting a need for further exploration into habitat preferences. Future research should focus on additional factors influencing night heron nesting preferences and explore other urban wildlife management strategies. Continued monitoring and adaptive management will be essential to ensuring the long-term success of conservation initiatives in dynamic urban environments.

Our results provide actionable insights for urban planning and wildlife management. Specifically, avoiding the planting of *F. microcarpa* and *S. terebinthifolius* in the Chinatown district, while promoting similar canopy characteristics around Lake Merritt, could effectively support night heron conservation efforts. This approach aligns with the broader goal of balancing urban development with wildlife habitat preservation. By integrating these findings into city planning and conservation strategies, we can better support the needs of both the local community and the wildlife that inhabits it.

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APPENDIX

Tree Characteristics

In analyzing tree characteristics of night heron nesting sites across Chinatown, significant differences were found between occupied and unoccupied trees in key variables, including canopy cover, canopy height, and diameter at breast height (DBH). Occupied trees showed significantly higher canopy cover (52.87) than unoccupied trees (31.85) ($t = -4.11$, $p < 0.001$), indicating that trees with denser canopy cover were more likely to be selected for nesting. However, canopy cover within a 100-meter radius did not show a significant difference ($t = -0.54$, $p = 0.56$).

For canopy height, there was a clear preference for shorter trees, as occupied trees had a lower mean canopy height (20.58) compared to unoccupied ones (14.73), with a significant t-statistic and a p-value ($t = -3.26$, $p < 0.001$). DBH also showed a notable difference, with occupied trees having a significantly larger mean DBH (21.75) than unoccupied trees (10.27), supported by a highly significant t-statistic and a p-value ($t = -7.54$, $p << 0.001$), suggesting that older trees, with larger trunks, are a key factor in nest site selection.

When examining specific tree species, *F. microcarpa* exhibited distinct patterns. Occupied trees had significantly lower canopy cover (66.78) compared to unoccupied trees (85.45) ($t = 2.62$, $p = 0.28$), indicating a preference for trees with less canopy cover within this species. Additionally, *F. microcarpa* trees showed significant differences in canopy cover within a 100-meter radius ($t = -3.20$, $p < 0.001$) and canopy height, where occupied trees had significantly lower heights (24.82) compared to unoccupied ones (53.83) ($t = 4.45$, $p < 0.001$). DBH did not differ significantly between occupied and unoccupied trees for *F. microcarpa* ($t = 0.89$, $p = 0.39$).

For *S.terebinthifolius*, no significant differences were found in canopy cover ($t = -0.17$, $p = 0.86$), canopy cover within 100 meters ($t = 1.36$, $p = 0.20$), canopy height ($t = 0.75$, $p = 0.46$), or DBH ($t = -0.92$, $p = 0.37$), indicating that these factors may not be as critical in nesting site selection for this species.

Overall, the results suggest that canopy cover and DBH are key factors influencing night heron nesting site selection in Chinatown, particularly for *F. microcarpa*. In contrast, canopy height and DBH do not appear to significantly influence the selection of *S. terebinthifolius* for nesting. These findings highlight the complexity of habitat preferences and species-specific requirements in urban nesting sites.

TABLE4

Table 1. Model Selection Based on AICc. Presents the AICc values, ΔAICc, and individual and cumulative model weights (*w*) for candidate models assessing predictors of night heron nesting site occupancy. Only models with weight ≥ 0.01 are shown, out of 638 total candidate models.

Model formula	ΔAICc	AICc	K	-2LogLike	*w*	Cumulative *w*
cnpy_cover + cnpy_height + ficus_tree + mode_AnyTrash + pepper_tree	0	95.366	6	-41.591	0.476	0.476
cnpy_height + dbh + ficus_tree + mode_AnyTrash + pepper_tree	4.234	99.600	6	-43.709	0.057	0.534
cnpy_height + ficus_tree + mode_AnyTrash + pepper_tree	5.055	100.421	5	-45.145	0.038	0.572
cnpy_cover + cnpy_height + ficus_tree + pepper_tree	5.369	100.735	5	-45.302	0.032	0.604
cnpy_height + ficus_tree + km2water + mode_AnyTrash + pepper_tree	5.460	100.826	6	-44.321	0.031	0.635
cnpy_cover + cnpy_height + ficus_tree + km2water + pepper_tree	5.838	101.204	6	-44.510	0.026	0.661
cnpy_height + ficus_tree + mode_AnyTrash + mode_predator + pepper_tree	6.220	101.586	6	-44.701	0.021	0.682
cnpy_cover + cnpy_height + dbh + ficus_tree + pepper_tree	6.396	101.762	6	-44.789	0.019	0.702
cnpy_cover + cnpy_height + ficus_tree + mode_human + pepper_tree	6.418	101.784	6	-44.800	0.019	0.721
cnpy_cover + cnpy_height + ficus_tree + mode_predator + pepper_tree	6.419	101.785	6	-44.800	0.019	0.740
ficus_tree + mode_AnyTrash + pepper_tree	6.554	101.920	4	-46.917	0.018	0.758
ficus_tree + km2water + mode_AnyTrash + mode_predator + pepper_tree	6.831	102.197	6	-45.007	0.016	0.774
cnpy_height + ficus_tree + mode_AnyTrash + mode_human + pepper_tree	6.913	102.279	6	-45.048	0.015	0.789
ccb100m + cnpy_height + ficus_tree + mode_AnyTrash + pepper_tree	6.921	102.287	6	-45.052	0.015	0.804
ccb100m + cnpy_cover + cnpy_height + ficus_tree + pepper_tree	6.980	102.346	6	-45.081	0.015	0.818
ficus_tree + km2water + mode_AnyTrash + pepper_tree	7.032	102.399	5	-46.134	0.014	0.832
ficus_tree + mode_AnyTrash + mode_predator + pepper_tree	7.237	102.603	5	-46.236	0.013	0.845

Table 2. Summary of Top Model Results. Summarizes the coefficients, standard errors, and confidence intervals for the generalized linear model (GLM) used to analyze these factors.

Predictor	Estimate	Std. Error	z Value	p-value
Canopy Cover	0.051	0.020	2.550	0.012
Canopy Height	-0.133	0.048	-2.771	0.006
F. microcarpa	8.481	1.563	5.420	<0.001
S. terebinthifolius	4.240	0.696	6.090	<0.001
Trash Presence	2.391	1.099	2.178	0.030

Table 3. Model-averaged coefficients. Presents model-averaged coefficients, including their standard errors and confidence intervals. This table highlights the influence of factors such as predator mode, human disturbance, *F. microcarpa* presence, *S. terebinthifolius* presence, DBH, canopy height, distance to water, and trash presence on night heron nesting site occupancy.

Parameter	Estimate	Standard Error (SE)	Lower Confidence Limit (CL)	Upper Confidence Limit (CL)
F. microcarpa	7.89	1.673	4.61	11.169
S. terebinthifolius	4.192	0.746	2.73	5.654
DBH	0.078	0.061	-0.041	0.197
Canopy Height	-0.112	0.055	-0.22	-0.003
Distance to Water	-2.778	2.075	-6.846	1.289
Trash Presence	2.349	1.097	0.199	4.498
Canopy Cover	0.048	0.022	0.004	0.091
Mean Canopy Cover within 100m	-0.064	0.116	-0.29	0.163

Table 4. *Summary of Canopy Cover, Canopy Height, and Diameter at Breast Height (DBH) for Trees in the Study Area*. **(A)** Summary statistics and statistical comparisons (t-statistics and p-values) for canopy cover, canopy height, and DBH of all trees, comparing occupied and unoccupied trees. **(B)** Summary statistics and statistical comparisons (t-statistics and p-values) for canopy cover, canopy height, and DBH of *F. microcarpa*, comparing occupied and unoccupied trees. **(C)** Summary statistics and statistical comparisons (t-statistics and p-values) for canopy cover, canopy height, and DBH of *S. terebinthifolius*, comparing occupied and unoccupied trees.

A.

Chinatown Trees (n = 464)				
Variable	Mean Occupied	Mean Unoccupied	t-statistic	p-value
Canopy Cover	52.87	31.85	-4.11	2.56e-04
Canopy Cover (100m)	8.18	7.80	-0.54	5.88e-01
Canopy Height	20.58	14.73	-3.26	2.43e-03

DBH	21.75	10.27	-7.54	1.89e-08

B.

Ficus microcarpa (n = 17)				
Variable	Mean Occupied	Mean Unoccupied	t-statistic	p-value
Canopy Cover	66.78	85.45	2.62	2.84e-02
Canopy Cover (100m)	11.38	8.23	-3.20	5.96e-03
Canopy Height	24.82	53.83	4.45	8.88e-03
DBH	28.31	30.00	0.89	3.86e-01

C.

Schinus terebinthifolius (n = 27)				
Variable	Mean Occupied	Mean Unoccupied	t-statistic	p-value
Canopy Cover	38.57	36.80	-0.17	8.61e-01
Canopy Cover (100m)	5.56	6.58	1.36	1.95e-01
Canopy Height	15.77	18.04	0.75	4.61e-01
DBH	17.58	16.13	-0.92	3.68e-01

Table 5. Tree species and their percent composition in the study area.

Tree Species	n	Percentage
Platanus hybrida	102	21.98
Tristaniopsis conferta	97	20.90
Ginkgo biloba	33	7.11
Schinus terebinthifolius	27	5.82
Fraxinus angustifolia	23	4.96
Pyrus calleryana	23	4.96
Ficus microcarpa	17	3.66
Magnolia grandiflora	11	2.37
Ulmus x	11	2.37
Pistacia chinensis	10	2.16
Liquidambar styraciflua	9	1.94
Tristaniopsis laurina	9	1.94
Platanus occidentalis	8	1.72
Rhus lancea	8	1.72
Eriobotrya deflexa	7	1.50
Cercis canadensis	6	1.29
Koelreuteria bipinnata	6	1.29
Lagerstroemia indica	6	1.29
Pyrus kawakamii	6	1.29
Zelkova serrata	5	1.08
Callistemon viminalis	4	0.86
Metrosideros excelsus	4	0.86
Prunus cerasifera	4	0.86
Quercus rubra	4	0.86
Pittosporum undulatum	3	0.65
Podocarpus gracilior	3	0.65
Celtis sinensis	2	0.43

Cinnamomum Camphora	2	0.43
Koelreuteria paniculata	2	0.43
Persea americana	2	0.43
Prunus serrulata	2	0.43
Tilia americana	2	0.43
Acer buergerianum	1	0.22
Quercus suber	1	0.22
Ulmus pumila	1	0.22
Unknown tree	3	0.65

FIGURES

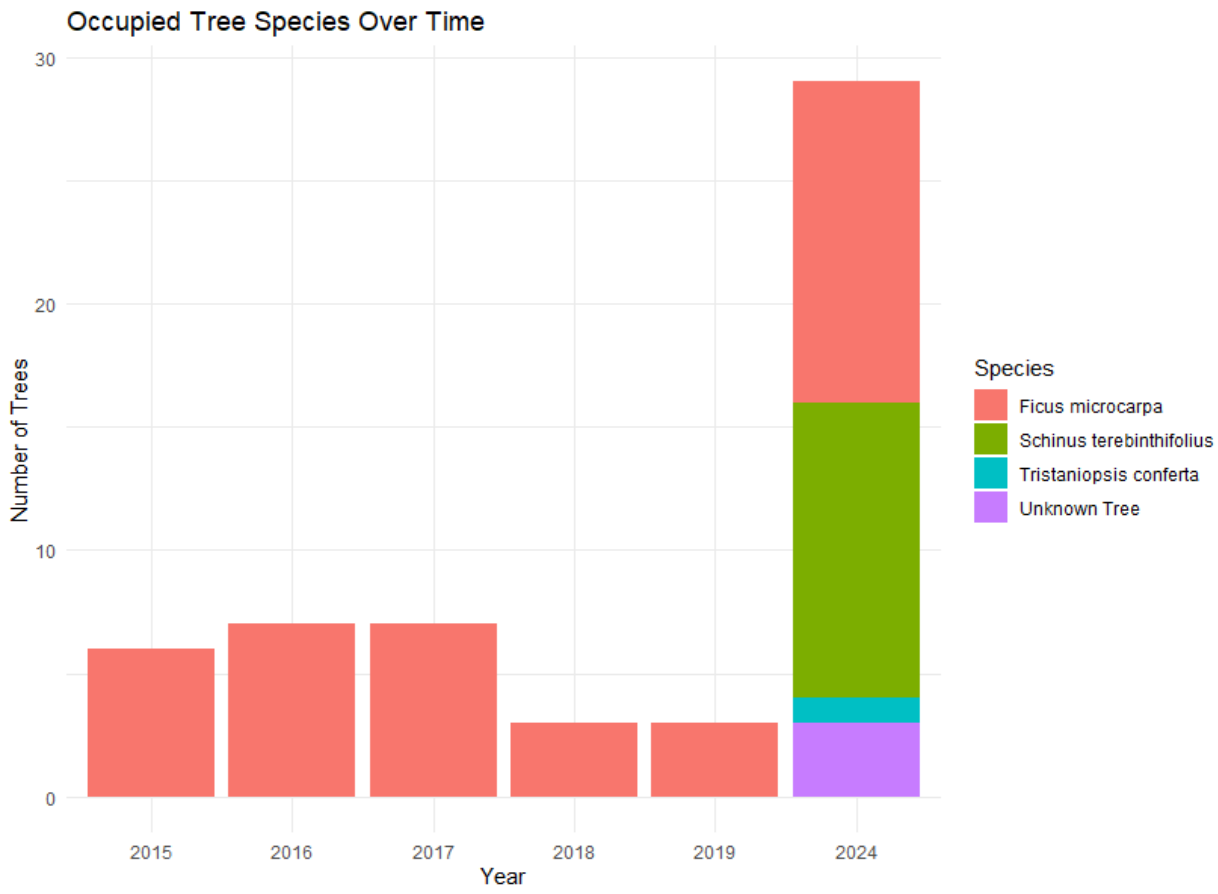

Figure 1. *Occupied Tree Species Over Time*. Species composition of trees occupied by night herons from 2015 to 2024, excluding the years 2020-2023 due to data gaps caused by the coronavirus quarantine. From 2015 to 2019, *F. microcarpa* (represented by the salmon color bars) was the predominant species. In 2024, both *F. microcarpa* and *S. terebinthifolius* (represented by salmon and teal-colored bars, respectively) were the most commonly occupied. The y-axis represents the number of occupied trees, while the x-axis indicates the year. n = 29.

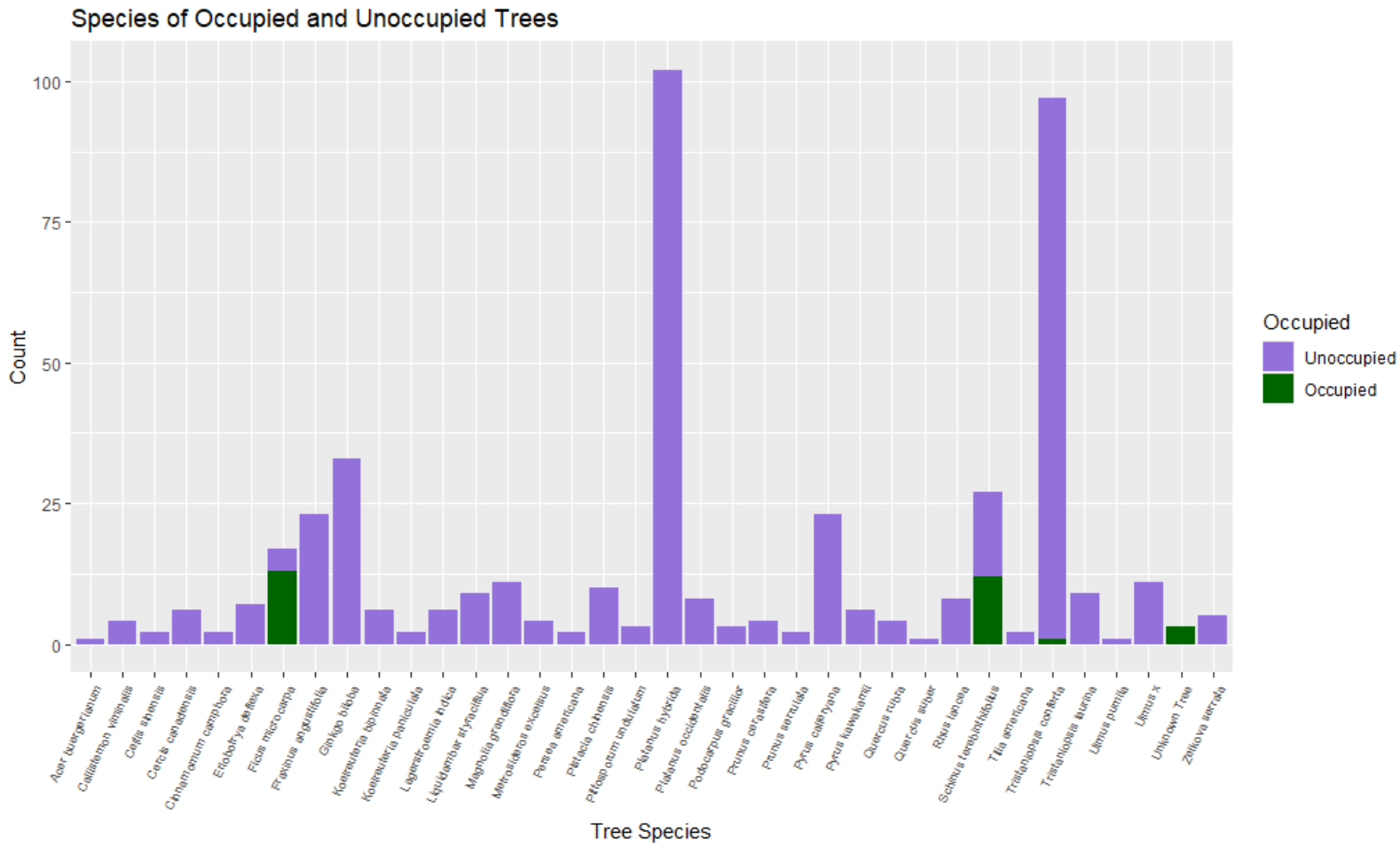

Figure 2. *Species Occupied and Unoccupied Trees*. Shown are the tree species composition used as colony trees (green) and non-colony trees (purple) in 2024. n = 464.

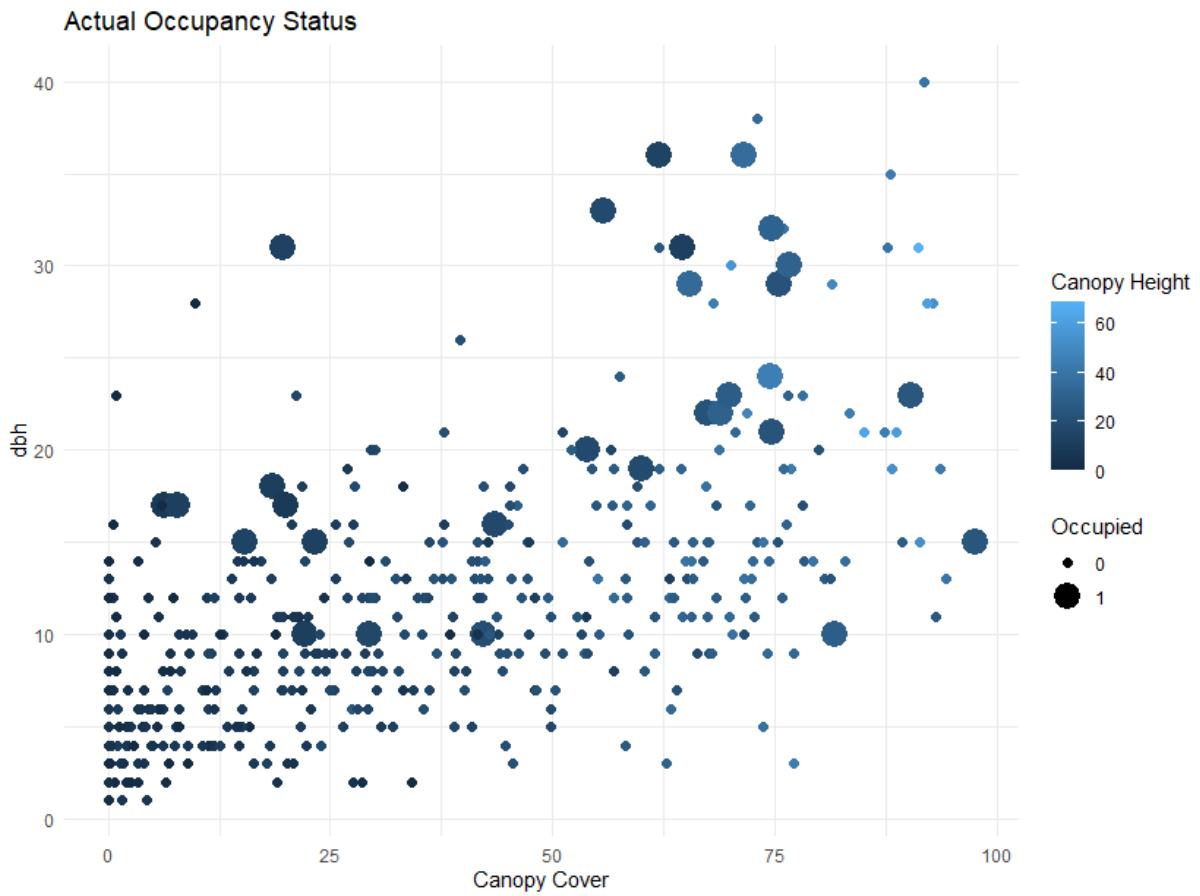

Figure 3. *Current Heron Nest Occupancy Status*. Scatter plot showing the correlation between canopy cover, canopy height, and DBH with night heron nesting site occupancy. Occupied sites are indicated by size, DBH is on the y-axis, canopy cover is on the y-axis, and canopy height is indicated by color.

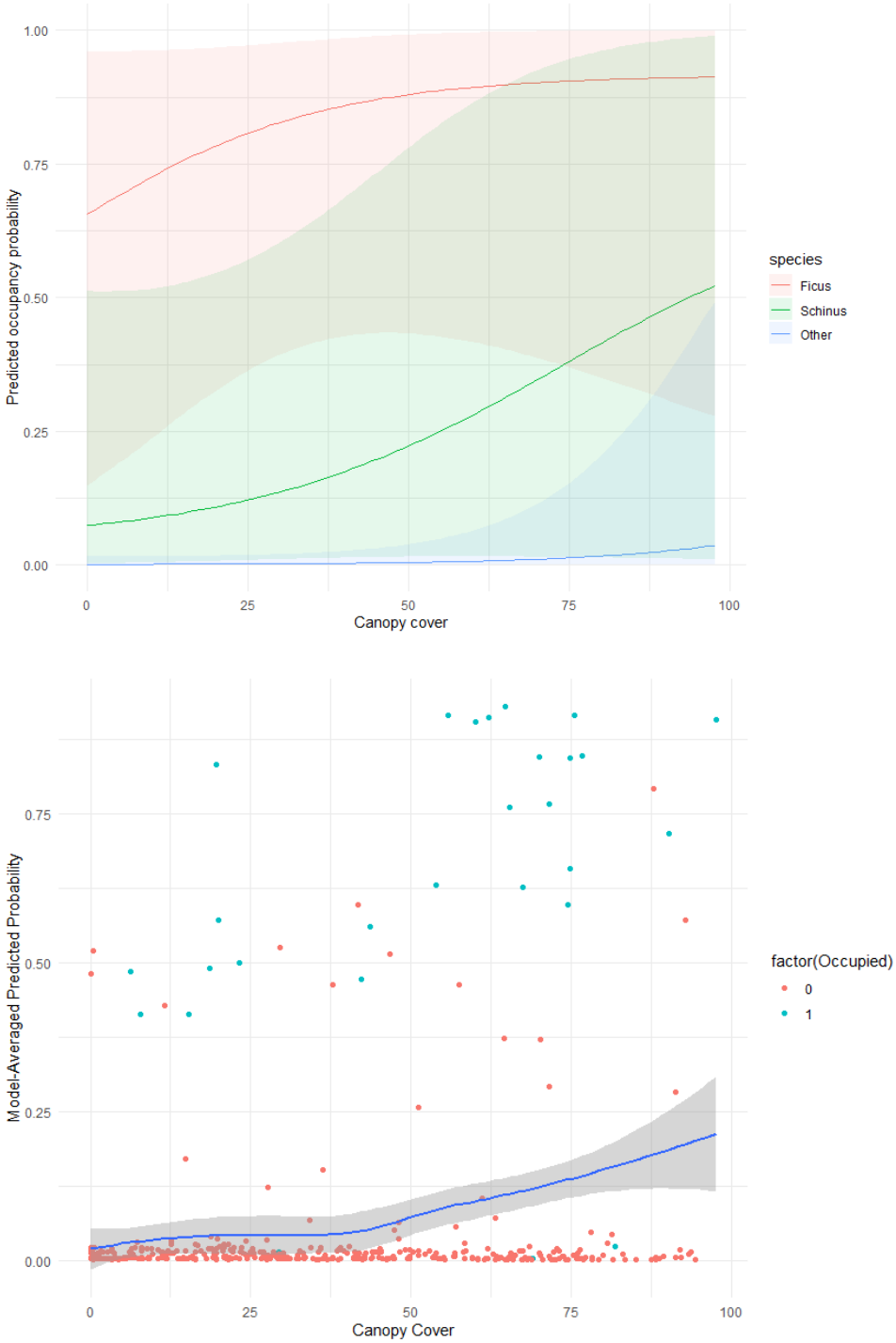

Figure 4. Marginal effects of canopy cover on night heron nesting occupancy (top) and the single predictor effect of canopy cover on occupancy probability (bottom). Shows increasing probability of occupancy with rising canopy cover.

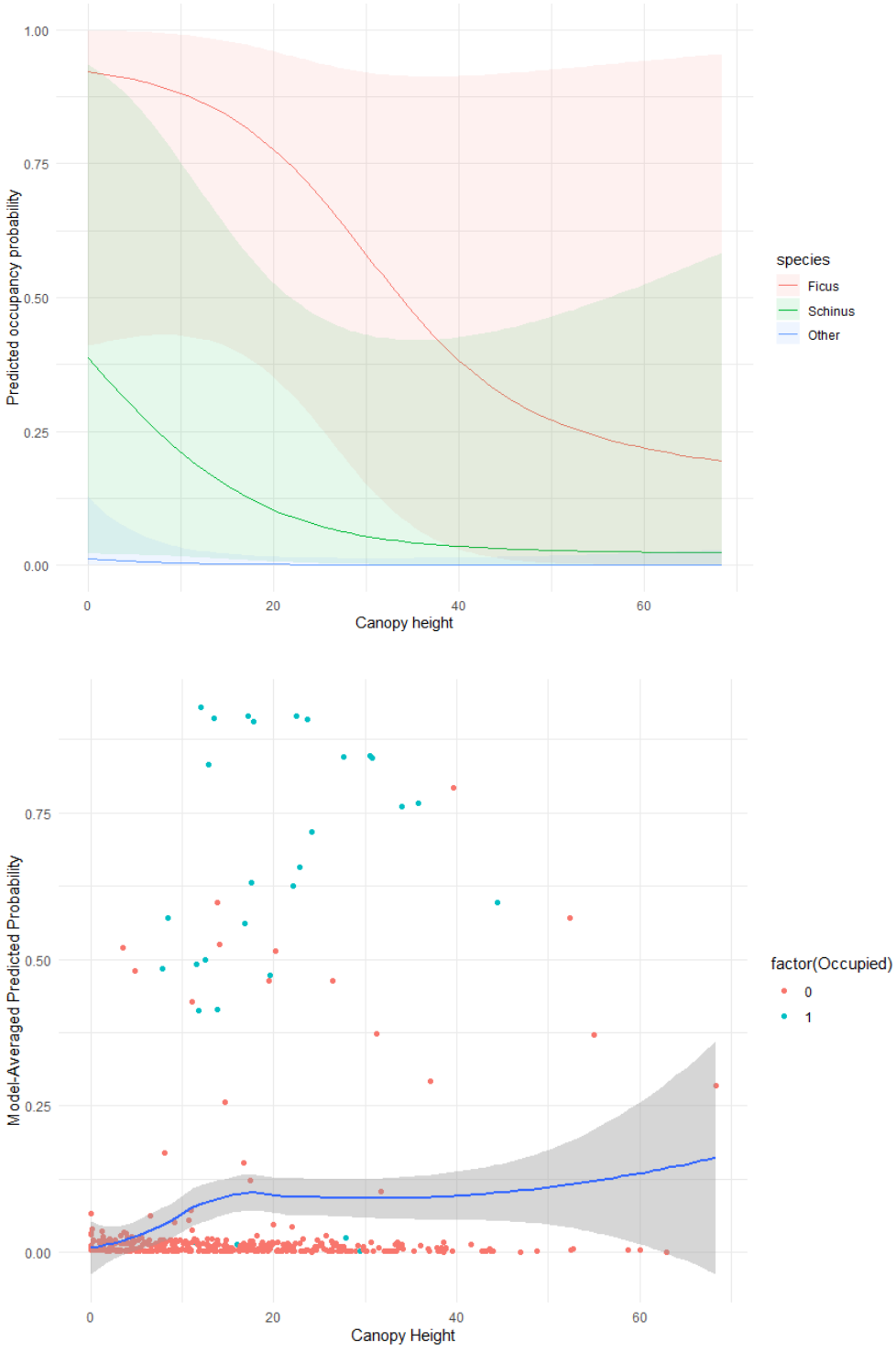

Figure 5. Marginal effects of canopy height on night heron nesting occupancy (top) and the single predictor effect of canopy height on occupancy probability (bottom). Illustrates preference for moderate-height trees.

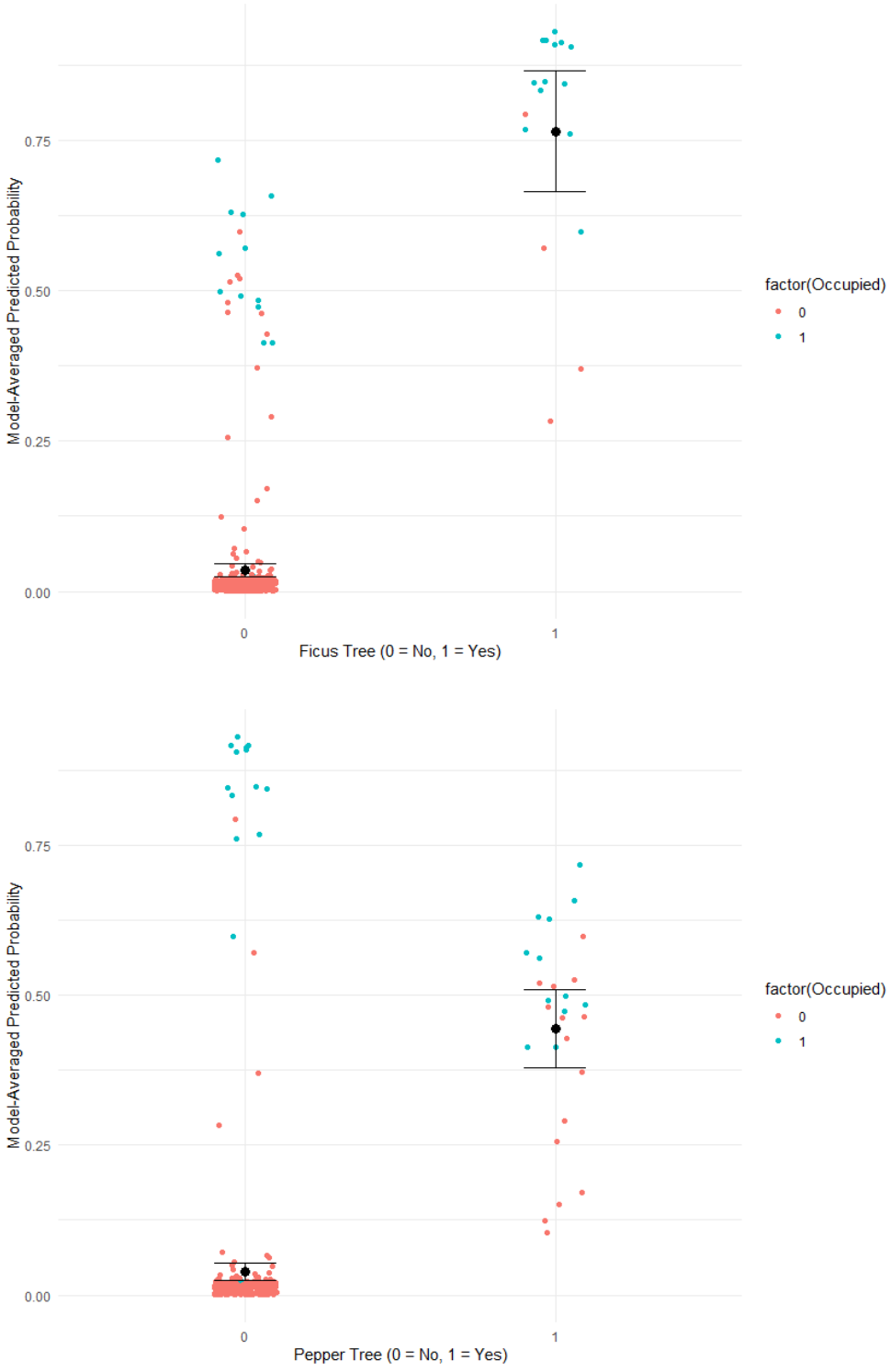

Figure 6. Effects of *F. microcarpa* (top) and *S. terebinthifolius* (bottom) on night heron nesting site occupancy. Both species are positively associated with increased occupancy.

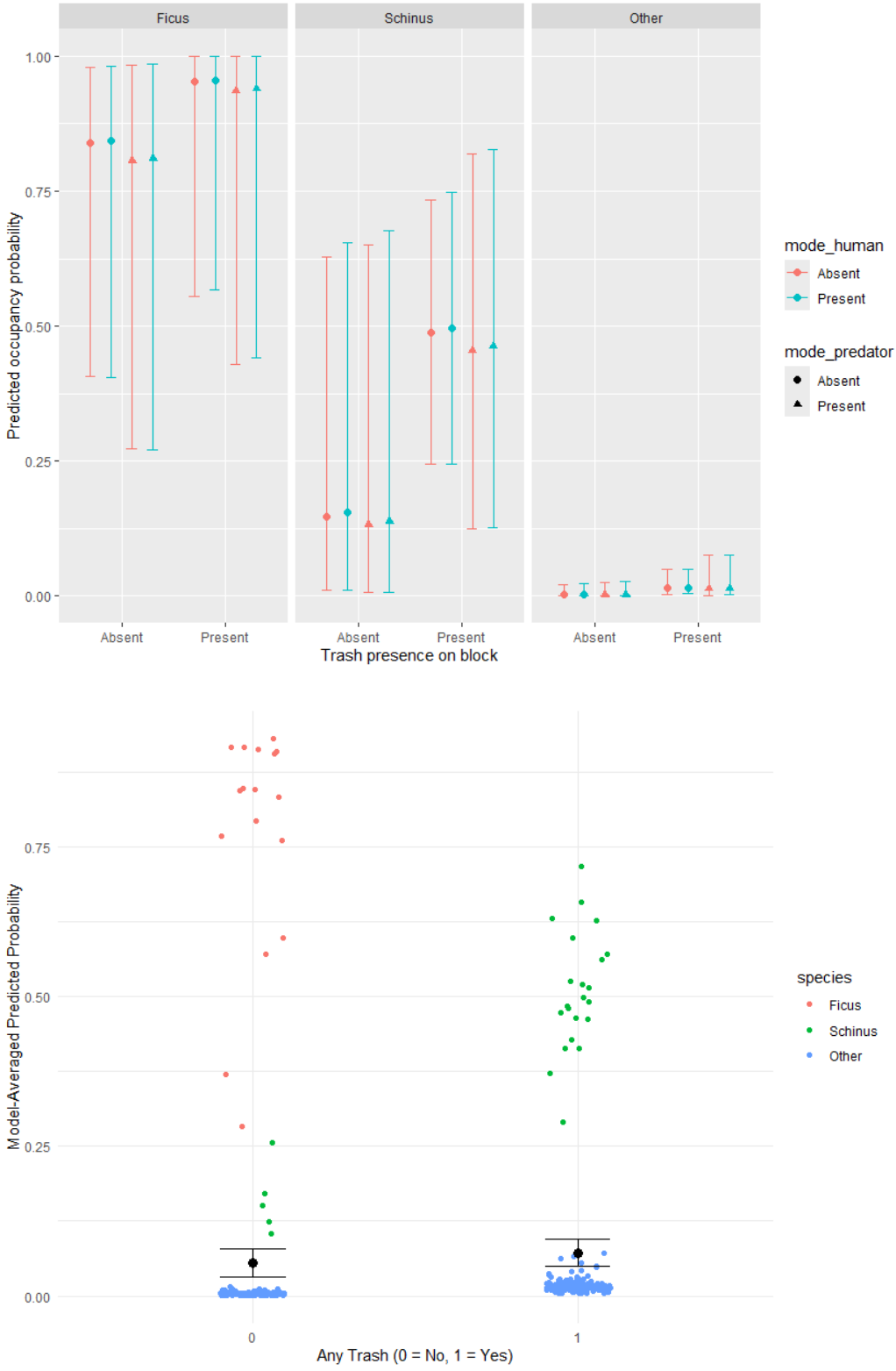

Figure 7. Categorical effects of trash on night heron nesting occupancy (top) and the single predictor effect of trash on occupancy probability (bottom). Shows slightly higher occupancy associated with sites where trash is present.

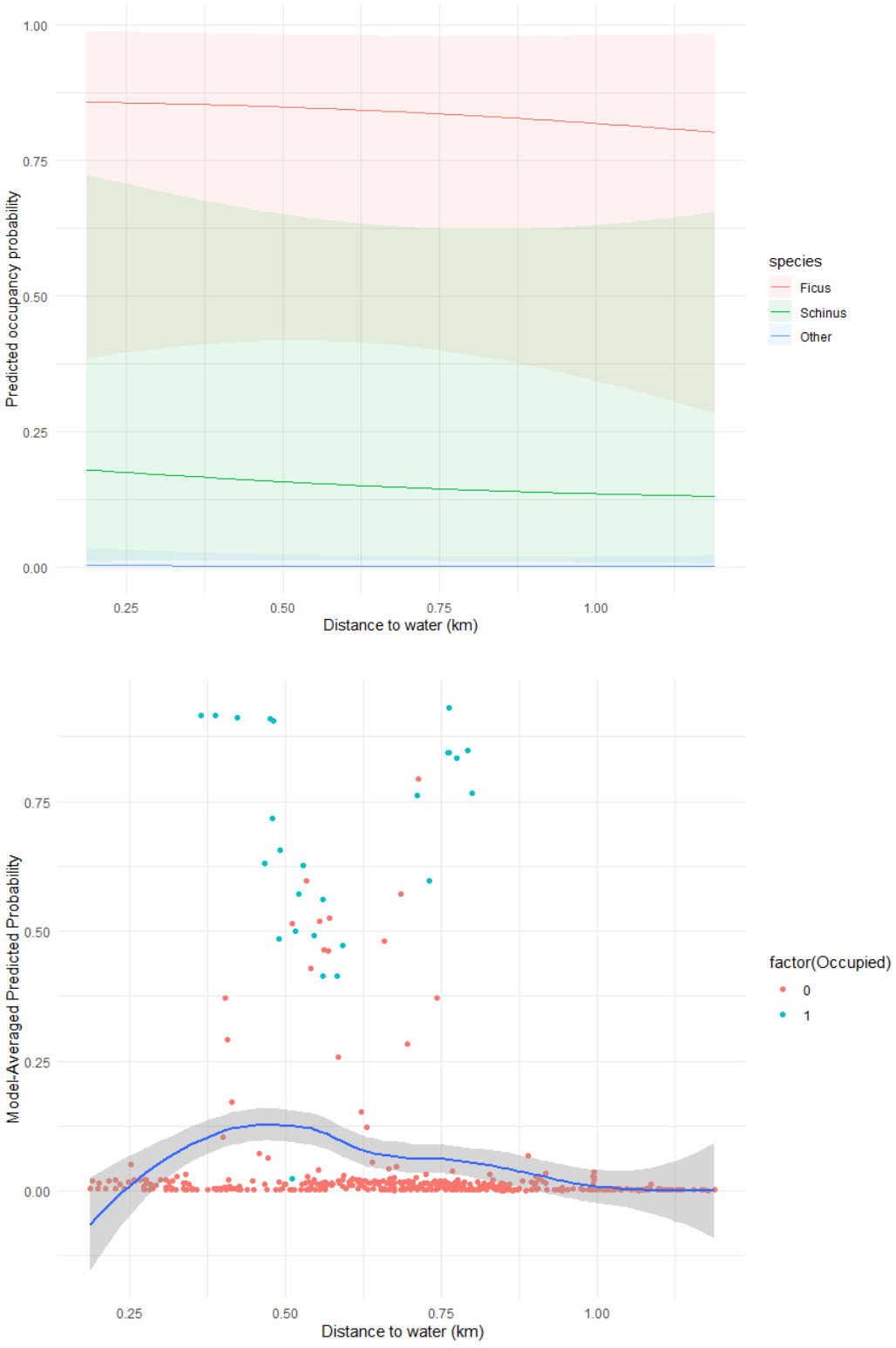

Figure 8. Marginal effects of distance to water (km) on night heron nesting occupancy (top) and the single predictor effect of distance to water on occupancy probability (bottom). Displays decreasing probability of occupancy as distance increases, but little to influence on occupancy.

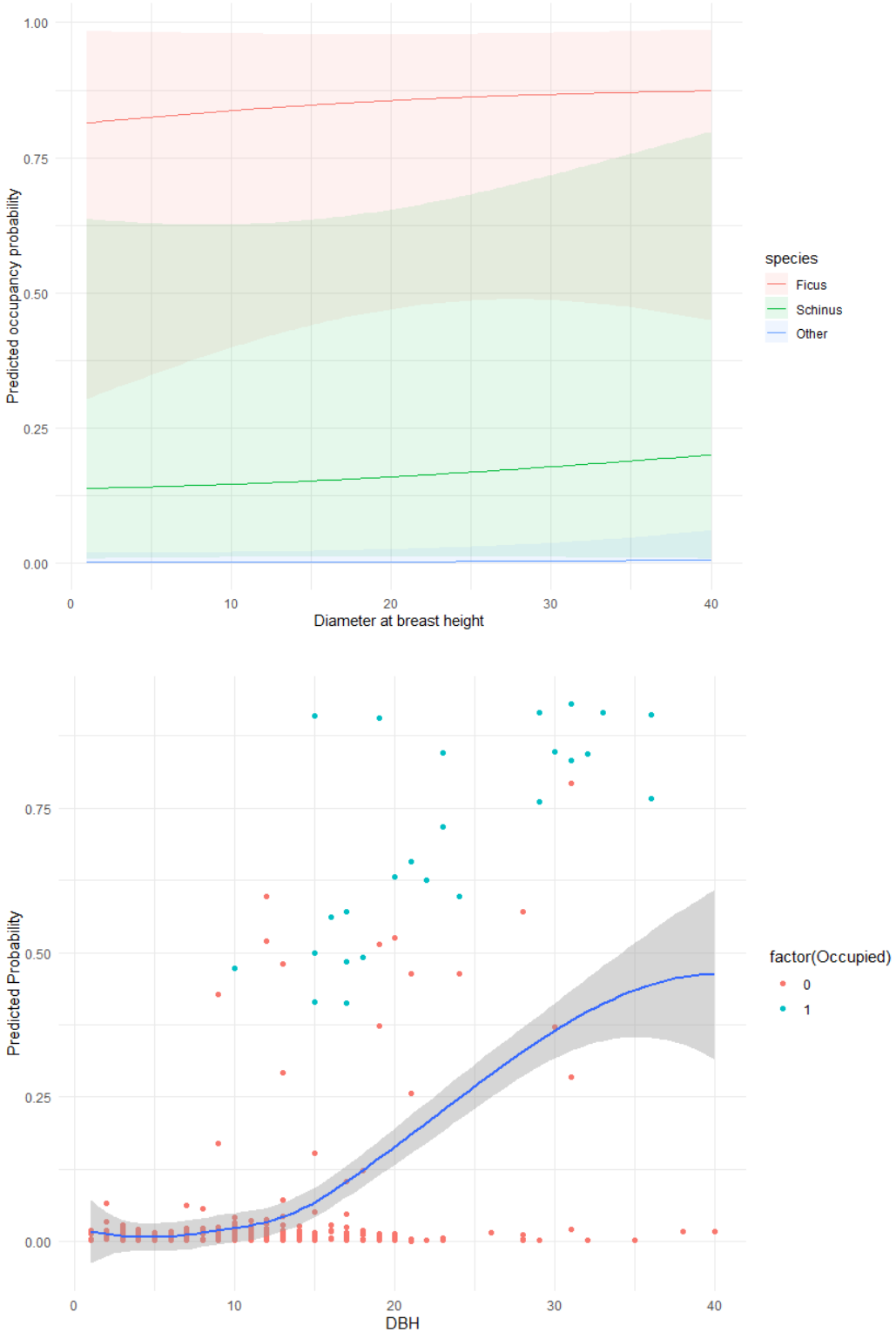

Figure 9. Marginal effects of DBH on night heron nesting occupancy (top) and the single predictor effect of DBH on occupancy probability (bottom). Displays increasing probability of occupancy with larger trunk diameters, but little to no influence on occupancy.

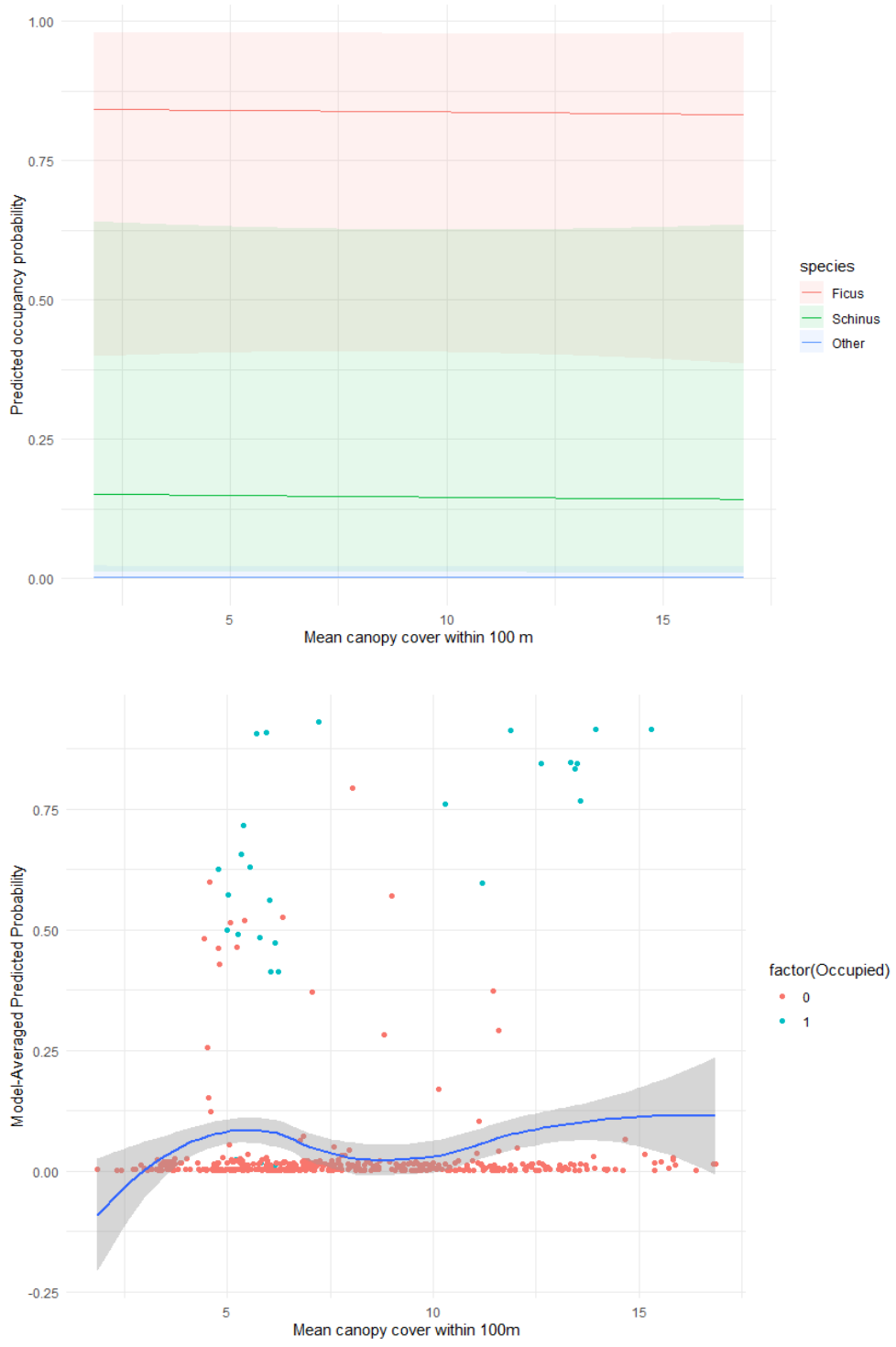

Figure 10. Marginal effects of mean Canopy cover within 100m on night heron nesting occupancy (left) and the single predictor effect of mean Canopy cover within 100m on occupancy probability (right). Displays decreasing probability of occupancy with increased nearby canopy cover, but little to no influence on occupancy.

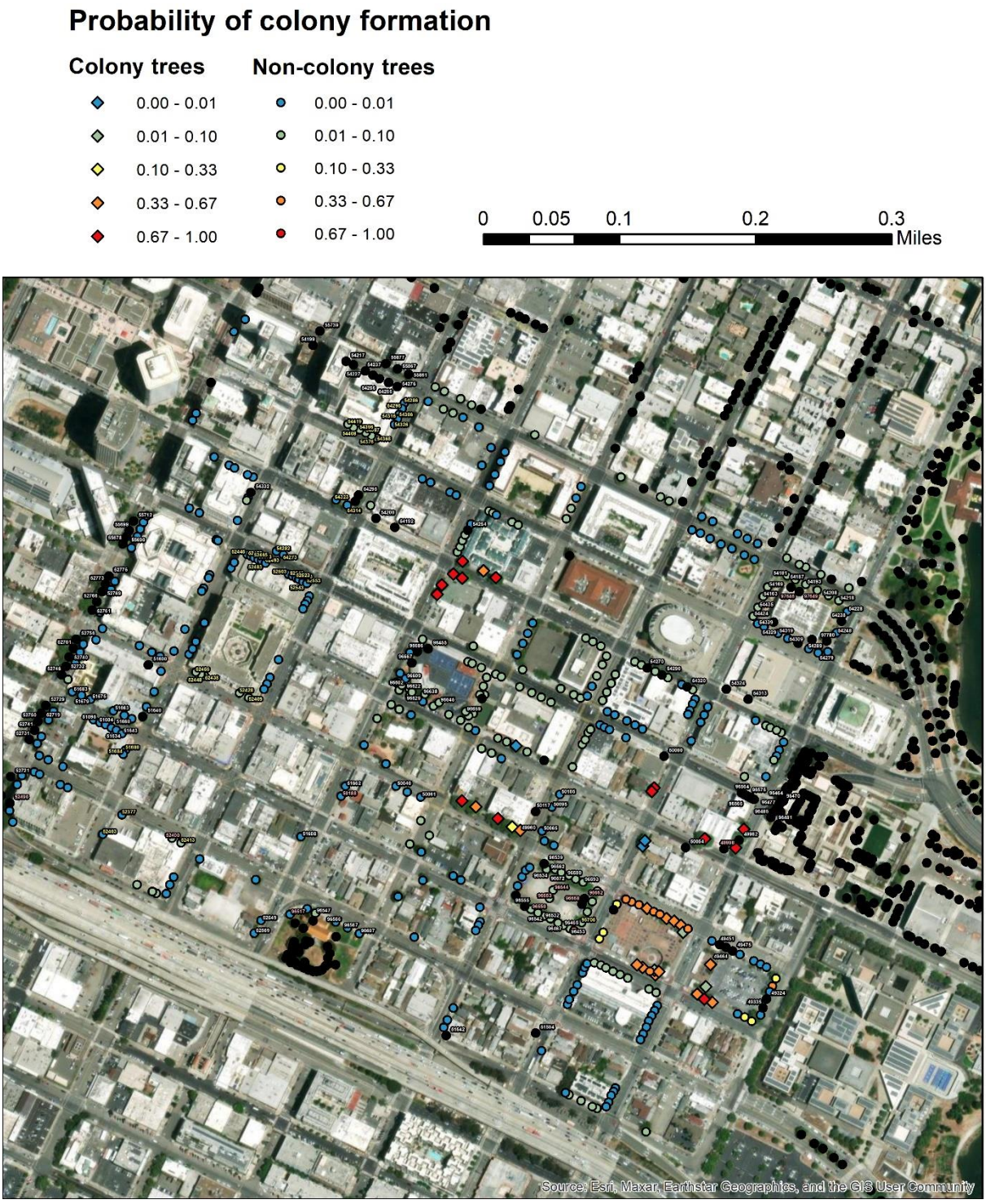

Figure 11. Map of probability of colony site formation in 2024 (probability of occupancy based on tree and block characteristics from 634 candidate models). Black dots are trees were not included in the set of surveyed trees and therefore predictions were not made to these trees.