DOES URBANIZATION FACILITATE THE ESTABLISHMENT OF INTRODUCED MONK PARAKEET (*MYIOPSITTA MONACHUS*) POPULATIONS?

by

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
CV	Coefficient of Variation
IMP	Percent Impervious Surfaces
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
TCC	Tree Canopy Cover
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USFS	United States Forest Service

ABSTRACT

Due to increased human presence and activities, urban environments tend to facilitate the introduction and establishment of some non-native species. Because of the habitat heterogeneity, varying resources, and an overall depauperate ecological community, urban environments may provide multiple underexploited niches for colonization by novel species. The Monk Parakeet (*Myiopsitta monachus*) is a prime example of an introduced species that has gone through the colonization process and successfully established breeding populations in urban environments. While much of this is due to urban areas being a common point of introduction (release) for exotic species, Monk Parakeets have not spread out beyond these urban environments. My two objectives were to determine what landscape features Monk Parakeet nests might be associated with and to further our understanding of why Monk Parakeets have so far remained in urban environments, as well as identify if there were any differences in these habitat associations across the United States. I used tree canopy cover and percent impervious surface data from the 2016 National Land Cover Database GIS layers, surface water features from the National Hydrography Dataset, and observations and location data from eBird to find nest locations that were then confirmed by Google Street View. I created buffered areas around each of 280 nest locations and random points (presumed absence locations) at three different radii: 100 m, 250 m, and 500 m. I found that Monk Parakeet nests are more likely to occur in areas with low tree canopy cover and greater heterogeneity of canopy cover. This pattern of nest site habitat association appears to be

roughly similar to their native range habitat, where they nested in tall trees scattered across the savanna. However, I also found that the probability of Monk Parakeet nests being present increased as the percent cover of impervious surface in the landscape increased. Even more revealing, average percent of impervious surface cover was greater around the confirmed nest sites than the absence sites, even though the absence sites were constrained to be 2 km from the nearest nest location. This shows that even within an urbanized or metropolitan area, Monk Parakeets seem to be more associated with areas that have the greatest cover of impervious surface. Availability of surface water features appeared to have very little effect on the presence of Monk Parakeets, although the data only included permanent water sources such as rivers, ponds, and lakes, not the smaller more ephemeral sources of water such as birdbaths or backyard swimming pools. I did not find a significant effect of either latitude or longitude on the relationship between any of the five environmental variables and the presence of Monk Parakeet nests, however, there was latitudinal and longitudinal-based variation in some of the five environmental variables that characterized landscapes surrounding Monk Parakeet nests. Based on the available data, the conclusions drawn from my study suggest that the establishment and growth of Monk Parakeets is facilitated by urban environments, and that they clearly rely on and have likely adapted to living in urban environments and will continue to do so into the future

I. INTRODUCTION

Human-facilitated invasive species are one of the greatest threats to global biodiversity, and the ecological impacts of these species have become a growing concern (Lim et al. 2003, Russello et al. 2008, Bonter et al. 2010, Vitousek et al. 2016). When introduced to a new environment, non-native invasive species can disrupt local ecosystem processes, transmit diseases, damage agriculture, and decrease native species abundances, in some cases leading to the extinction of endemic species (Clavero et al. 2005, Rodríguez–Pastor 2012). Urban environments, due to high human presence and increased level of activity, especially those related to transportation and trade, can both filter and facilitate the introduction of these species. Urban environments can provide a variety of areas for the introduced species to occupy due to the habitat heterogeneity of an urban landscape and the food resources vary in both overall availability and composition. The urban environment also tends to have a more depauperate ecological community compared to surrounding natural habitats, which can provide many opportunities and challenges for species attempting to establish themselves. (Sol et al. 2017). Because of these conditions, urban environments can provide multiple underexploited niches for colonization by introduced species.

One introduced species that has successfully gone through the colonization process is the Monk Parakeet (*Myiopsitta monachus*). Monk Parakeets are a medium-sized parrot species (family Psittacidae), ecological generalist in diet and habitat, and have established breeding populations in the urban environments of multiple cities within the United States (Figure 1). It is one of many parrot species that have been introduced outside their natural geographic range, often taking advantage of urban areas and human-modified habitats to establish thriving populations in many cities around the world (Sol et al. 2017, Uehling et al. 2019).

In their native geographic range, Monk Parakeets are found in the semi-arid savanna and woodland regions of Argentina, Brazil, Uruguay, Paraguay, and Bolivia, preferring open grasslands with patches of tall and sturdy trees to build their nests, including Mandovi (*Sterculia apetela*), Piúva (*Tabebuia* spp.), Tala (*Celtis* spp.) and palm trees (Burger and Gochfeld 2005, Bucher and Aramburú 2014). They forage both in trees and on the ground, and their generalist diet consists of seeds, fruits and berries, leaf buds, and blossoms from a variety of different plants and shrubs (Burgio et al. 2020). They are a highly gregarious or social species, foraging and nesting in large groups. Unlike other members of the Psittacidae family that are cavity nesters, Monk Parakeets will build their own nests, weaving together woody material to construct a large nest. These nest structures can be built to have multiple cavities and openings for many mated pairs or individuals that live together within the superstructure, with some of the nest structures in Argentina containing over 200 nest chambers (Bucher et al. 1991, Eberhard 1998, Avery and Lindsay 2016, Burgio et al. 2020). Depending on the size of the group or colony, multiple nest structures are built in close proximity to each other either on the same structure as space allows or on another nearby structure (Avery and Lindsay 2016, Burgio et al. 2020).

An increase in agriculture and introduction of *Eucalyptus* trees occurred within parts of the native range in the late 1800's. Monk Parakeets began to utilize the eucalyptus trees as nesting structures, almost exclusively nesting in them as they were much taller and stouter than the native trees. Because of this, Monk Parakeets became closer to human settlements, which gave them easier access to the food resources from the surrounding agricultural and live-stock areas (Bucher and Aramburú 2014, Navarro et al. 1992, Russello et al. 2008). Because of this proximity to human settlements and cropland and the damage from foraging on those crops, Monk Parakeets are now considered an agricultural pest species throughout their native geographic range. They eat a wide variety of cultivated grains and fruits, resulting in crop-loss between 2% to 45% on an annual basis (Navarro et al. 1992, Davis 1974, Rodríguez–Pastor 2012).

Birds are among the more common taxa to be introduced to new locales, with species from all over the world being sought after for a variety of reasons, as pets, for hunting, and for aesthetic purposes. Almost two thirds of all introduced bird species come from only six families: Anatidae, Columbidae, Fringillidae, Passeridae, Phasianidae, and Psittacidae (Duncan et al. 2003). As a group, the parrot family seems to be over-represented on the world-wide list of invasive bird species, and the Monk Parakeet is among the most transported bird species in international pet trades, both the legal and illegal ones (Bucher et al. 1991, Burger et al. 2009, Burgio et al. 2014, Uehling et al. 2019). Once transported to a new location, some of these pets are inevitably introduced to novel habitats, either by escaping from captivity or being intentionally released.

The earliest confirmed breeding populations of Monk Parakeets in the United States were first observed in New York in the late 1960's (Neidermyer et al. 1977, Lund 2015). This initial release of Monk Parakeets is believed to have occurred in 1967, with over 2,000 birds escaping from a damaged shipping container at the John F. Kennedy airport in New York City and then surprisingly thriving in the large metropolitan area, subsequently expanding, and colonizing other nearby urban areas (Lund 2015). Likely, other releases or escapes occurred elsewhere independent of the NYC airport event, as owners of unwanted exotic pets, instead of finding a new owner or suitable home, will occasionally release them into the wild, assuming they will survive on their own once in nature or die off. In Austin, Texas, the first Monk Parakeets are thought to have escaped from parked vehicle downtown in the early 1970's (Lund 2015). By the 1980's, Monk Parakeets were observed in the Hyde Park neighborhood in Chicago, Illinois and enjoyed some minor legal protection from Harold Washington, the mayor at the time, who had a tree outside his residence occupied by Monk Parakeets (Hyman and Pruett-Jones 1995, Tweti 2008). Across the United States, roughly 64,000 birds were 'introduced' to various cities from 1968-1972, with almost a third of the releases occurring around 1971 (Lever 1987). The unique structure of their nest and that they build it themselves is thought to be partially responsible for the species' survival and spread outside of its native range, as the nest structures can maintain warmer temperatures in the colder months at higher latitudes (Viana et al. 2016).

When Monk Parakeets were first observed in different parts of the United States, their potential to become an agricultural pest was a major concern (Davis 1974). In the early 1970's, the United States Fish and Wildlife Service (USFWS), fearing potential ecological and economic damage, established a retrieval and removal program to reduce populations of Monk Parakeets in the United States. Between 1970 and 1975, there were confirmed sightings of individual Monk Parakeets across the country, but the most active retrieval programs were in New York, California, Virginia, and New Jersey. Retrieval programs were relatively successful, resulting in a 44% overall reduction in population size at targeted locations (Neidermyer et al. 1977). As the retrieval programs have ended, aside from small populations in California and Florida causing occasional agricultural damage, Monk Parakeets have mostly been confined to urban areas, unlike in their native range where they are now found in both urban and rural environments (Davis 1974).

The Monk Parakeet's choice of nesting location has proven to be the more problematic issue rather than potential agricultural damage from foraging. In urban areas, nests are commonly built on anthropogenic structures like light poles, communication towers, electric utility structures, and other infrastructure which physically resemble the tall trees that they build their nests on in South America (Burger and Gochfeld 2009, Burgio et al. 2014, Reed et al. 2014). In some cities in Florida, about 80% of surveyed nests were constructed on artificial structures, while the remainder were placed in trees (Avery and Lindsay 2016). Electrical utility structures have a variety of small spaces, platforms, and openings depending on the size and design of the structure, and these provide ample places to insert woody vegetation to begin the nest-building process (Burgio et al. 2014, Reed et al. 2014). However, there are several negative impacts arising from nests built on infrastructure, including power disruptions or outages, damage to electrical equipment, and costs associated with nest removal (Reed et al. 2014). Common methods used to non-lethally remove colonies from electrical structures include repeated nest destruction or removal to discourage the birds from re-nesting, limiting access to the electrical line where it connects to the utility pole (the initial point where a nest is typically constructed), and the use of the oral contraceptive diazacon, which has been shown to reduce the number of viable eggs and chicks by up to 68% (Burgio et al. 2014, Avery and Lindsay 2016). Previously, some city governments have initiated programs to capture and euthanize entire colonies of Monk Parakeets to prevent damage to electrical structures. However, local groups such as the Audubon Society and other birding organizations have opposed such programs due to the popularity of the Monk Parakeets (Silverman 2009, Goldenstein 2017).

The success of these various introduced bird species, such as the Monk Parakeet, is not solely due to their multiple introductions throughout the United States. Once an introduced species is brought or arrives in an urban environment, those individuals need to find suitable habitat to establish themselves. Urban areas can provide a variety of environments for the introduced species to occupy due to the habitat heterogeneity of an urban landscape, providing multiple niches for colonization (Sol et al. 2017). However, the establishment process can be challenging due to a variety of factors influencing resource and habitat availability, which can filter out species that are unable to adapt to the urban environment (Sol et al. 2013). Within an urban environment, food sources are generally more predictable than in natural environments, but are often widely variable in composition, including both native and non-native vegetation, human generated waste, and semi-random food sources like bird feeders. Generalist species tend to have a higher chance of survival in urban environments with regard to resource acquisition, being able to find food from a variety of sources, some of which could vary spatially and temporally (Sol et al. 2013). These introduced species can readily take advantage of any sources of available food and thus sometimes avoid competition with native species (Sol et al. 2013, Sol et al. 2017). There are also fewer natural predators within an urban environment, due to decreased natural habitat and a wide array of external factors (traffic, noise, light pollution, and general environmental pollution) that would discourage the presence of predators (Cadotte et al. 2017, Sol et al. 2017). However, some predatory animals have also adapted to urban environments, such as Peregrine Falcons (*Falco peregrinus*), known to nest on towers or skyscrapers and actively hunt for prey (e.g., pigeons) within cities. This high-resource and comparatively low-predator environment can facilitate the process of recently introduced species establishing in a new environment.

Objectives

Previous studies have examined the impacts and ecology of Monk Parakeets in the United States, primarily focusing on their population growth and potential for economic damage via electrical structure damage and crop damage (citations above). A few studies have examined the habitat features that Monk Parakeets associate with outside of their native habitats (Sol et al. 1997, Davis et al. 2014). However, no study has identified the important habitat features that are associated with the Monk Parakeet nest location, particularly at a landscape scale. The main objective of my study is to better understand the habitat features that are associated with successful nest site selections in the United States. By better understanding the habitat or landscape features that Monk Parakeets associate with, especially regarding their nesting locations, we can better understand their population growth and geographic spread. Such knowledge could then be applied to prevent unwanted Monk Parakeets colonies from forming in sensitive areas or predicting how they would spread in an urban setting. In addition, my study will also contribute to our expanding knowledge base concerning how invasive species are able to use human-modified landscapes and habitats to establish populations. As humans continue to urbanize the planet in many and various locations, the spread and establishment of invasive species will likely become an even more commonplace occurrence.

Research Questions

Below I describe two research questions that were intended to address my objective and guide my research.

(1) Are there specific habitat or landscape features that are associated with nest site selection of Monk Parakeets? I determined whether Monk Parakeet nests are associated with specific environmental features or characteristics such as woody vegetation and anthropogenic surfaces. The former represents the availability of natural or semi-natural habitat whereas the latter represents urbanization in general. Although Monk Parakeets use tall native tree species and introduced eucalyptus trees in their native South American range, in the United States and other areas of introduction, they tend to build their nests in artificial structures such as utility towers and other infrastructure (Navarro et al. 1992, Russello et al. 2008, Bucher and Aramburú 2014, Reed et al. 2014). Rather than focusing on nesting support structures (which are well documented), my study examined the surrounding environment of the nest structure locations. I sought to identify the factors of the surrounding environment that make one nesting site more appealing than another potential but unused site, such as the availability of woody material for nest building or the level of urbanization and associated resources such as food availability. Because Monk Parakeets require woody material to construct their nests, there should be a relationship between canopy cover and availability of nesting material and hence a positive association of nest site locations with canopy cover. Moreover, canopy cover in the form of trees likely also provides foraging Monk Parakeets with a place to perch and seek refuge (when away from the nest structure) as well as a potential food source from some fruit-bearing tree species. To test for a scaling effect, I examined habitat associations over multiple spatial scales from the area immediately surrounding a nest structure (e.g., within 100 m) up to a landscape scale of 500 m (see section on Study Design and Methodology).

(2) Do different populations of Monk Parakeets across the United States associate with landscape (habitat) features in different ways? I determined whether the habitat associations of Monk Parakeets are consistent or different between distinct populations throughout the United States. In their native range in South America, Monk Parakeets inhabit areas that are relatively similar in climate and habitat. However, in the United States, there are thriving populations of Monk Parakeets in warmer climates such as in Texas and Florida, but also in much colder areas such as New York and Illinois. Their nest structures are thought to play a significant role in their ability to survive winter in those colder areas, but it is also possible that populations in different climates inhabit different types of landscapes regarding availability of natural vegetation and urbanization (Davis et al. 2014, Viana et al. 2016). I examined the similarities and differences in landscape features between the different metropolitan areas occupied by Monk Parakeets around the United States.

II. METHODS

To conduct this study, I used a citizen science database (eBird) to acquire spatial locations of Monk Parakeet nests and GIS databases derived from remote-sensing imagery to obtain information on landscape features around the nest locations. The statistical analysis then involved comparing actual nest locations to nearby random absence points. Further details on methodology are presented below.

Data Sources

eBird

eBird is an online free-to-use citizen-science database in which observers upload sightings of different species of birds typically seen during a deliberate outing to observe birds (i.e., a birdwatching trip). Anyone may create an account and submit their data/observations (known as a "checklist") and view checklists submitted by other users. These checklists include information such as the number of each bird species observed, location, date, time, and level of survey effort/duration, as well as any photos, videos, or audio recordings that the observer may have obtained during the outing. Observers can add additional information about the environmental conditions or specific behaviors of the birds in their uploaded report. Some of the additional information includes a "Breeding and Behavior Code" that is intended to describe the birds' reproductive status. To maintain a high level of data quality, observations are put through a series of automated filters that compare the submitted data to typical observations based on the area and date. Any unusual observations or uploaded media are flagged for review by local or regional experts who then contact the submitter to either verify the sighting or update the checklist information. Once the checklist has been accepted, the data are added to the eBird database for anyone to access. eBird is managed by the Cornell Lab of Ornithology and is the most extensive and intensive database on bird distribution (Sullivan 2009).

NLCD Percent Developed Imperviousness

The Percent Developed Imperviousness (IMP) dataset of the National Land Cover Database (NLCD) is a rasterized geospatial data layer created using multi-spectral imagery from the Landsat satellites (Yang et al. 2018, Jin et al. 2019, Homer et al. 2020). This dataset represents the percentage of impervious surface (primarily concrete, asphalt, and building cover), as well as the degree of urbanization. In this layer, the United States is covered in a grid with a 30 x 30 m pixel resolution, wherein each pixel is assigned a value ranging from 0-100% in 1% increments. Data are available for 2001, 2006, 2011, and 2016, but for this study, only the most recent data from 2016 were used.

NLCD USFS Tree Canopy Cover Cartographic

The NLCD U.S. Forest Service Tree Canopy Cover (TCC) is a rasterized geospatial dataset created using multi-spectral Landsat imagery (Coulston et al. 2012). This dataset indicates the percent tree canopy cover and for this study, TCC is used to determine available woody vegetation that could be used for either nest building or as the structure to build on. In this layer, the United States is covered in a grid with a 30 x 30 m pixel resolution, wherein each pixel is assigned a value ranging from 0-100% in 1% increments. Data are available for 2011 and 2016, but for this study, only the most recent data from 2016 were used.

USGS National Hydrography Dataset

The U.S. Geological Survey National Hydrography Dataset (NHD) is a dataset of naturally occurring and constructed bodies of water and associated features (USGS 2016). The NHD is divided into several layers. NHD Flowline contains the paths that compose linear water drainage such as rivers, streams, and pipelines. NHD Waterbody contains polygons representing larger bodies of water such as lakes and estuaries. NHD Line represents linear hydrographic landmark features used for cartographic representation such as bridges or dams. NHD Point represents point hydrographic landmark features such as springs and wells. NHD Area represents areal hydrographic landmark features such as the oceans or broad inundation areas. The NHD is continuously updated, but the data used for my study were compiled and downloaded in 2019-2020.

Acquiring and processing eBird data

To identify Monk Parakeet nest locations, I downloaded the available observation (“checklist”) data from eBird in April 2020, which contained 240,716 observations worldwide. Because I was only interested in nests in the United States, I removed all observations outside of the USA. This reduced the number of observations to 89,150 nationwide. Because the NLCD IMP and TCC datasets were from 2016, I only used eBird observations from the past ten years, which further reduced the number of observations down to 75,228. This dataset was then uploaded to ArcGIS Pro (v2.6.3) to visually locate the observation points. Within ArcGIS Pro, I further filtered out observations based on the Breeding and Behavior Code, keeping observations that specifically indicated a nest or nest-building behavior. I also filtered observations based on whether the observer had supplied any comments in their checklist, specifically species comments that might have provided a nest location, as not all observers might include the Breeding and Behavior Codes in their checklist but still describe the presence of a nest. Additionally, some eBird observers provide rich media, such as photographs or videos, that I also used to verify the presence of a nesting structure that might not have been identified with a Breeding and Behavior Code, so those observations were also retained.

Once I had these potential nest locations imported into ArcGIS, I verified whether each location had a Monk Parakeet nest. eBird codes checklists as a single latitudinal-longitudinal point, even if the birding event occurred over a relatively large area (as when a birdwatcher is walking), so even if a checklist listed a Monk Parakeet nest, I could not be sure that the nest was actually located at that point. Due to the COVID-19 pandemic, my options for safely traveling to verify nests in person were extremely limited, so instead I utilized Google Street View to positively identify nest locations. I would locate the potential nest location from eBird, then use Google Street View to inspect the area and attempt to find the nest. Locations in Google Street View can have multiple years to view depending on when Google was conducting their surveys, so I only looked at views after 2010 to correspond with the eBird and NLCD data. In some cases, Google Street View did not cover an area where eBird observations suggested a nest was present. If no rich media were available to confirm the nest and there was no way to visually confirm the nest with Google Street View, I omitted the observation. After filtering from the 75,228 observations in this way, I was able to confirm the locations of 285 Monk Parakeet nest locations.

Within ArcGIS Pro, I created buffered circular areas around each nest location at three different radii: 100 m, 250 m, and 500 m. As is typical for landscape-scale studies of habitat associations, using multiple spatial extents allows for an examination of a scaling effect. The 100 m buffer would inform me about the environment immediately surrounding the nest structure and hence the area of highest use by birds in the nest colony. The 250 m buffer distance checks for the presence of potential Monk Parakeet colonies (i.e., multiple nearby nests). As Monk Parakeets are a social species, there will occasionally be multiple nesting structures near each other, either built on the same telephone poles, lights, or transmission towers or on an adjacent structure. Multiple nest structures within 200 m of each other were considered as part of a single colony due to their proximity (Burger and Gochfeld 2005). It is difficult to know exactly how Monk Parakeets use multiple adjacent nests in a colony situation, and whether each nest is independent of the other ones in being used and occupied by different individuals. Thus, the ecological and statistical independence of closely spaced nests (within 200 m) is questionable, and such nests would have substantial overlap of buffers if considered separately. To prevent these potential issues, I identified nest site locations that were within 500 m of each other (the distance of two 250 m buffers overlapping), and then randomly eliminated nest locations from such sets leaving only one for subsequent analysis. With this further filtering of the Monk Parakeet data, I ended up eliminating only five nests that were too close to other confirmed nest locations, which reduced my final number of Monk Parakeet nest locations to 280 (Figure 2). The greatest buffer distance of 500 m represents a wider area which the Monk Parakeets might use to forage or occasionally acquire nesting materials.

To statistically examine my two study questions, I used multiple logistic regression (see Statistical Analysis section below) which requires binary data, and in my study comes in the form of presence and absence of Monk Parakeet nests. To achieve this, I created 280 absence locations, to equal the number of confirmed nest site locations. In ArcGIS Pro, I created a 2 km radius circular buffer around each confirmed nest location, to ensure that I had a large enough area to randomly place an absence location without it being too far away from where the confirmed nest was located. Once I had created these 2 km buffers, I then clipped out the inner 500 m to ensure that the randomly generated absence point and the confirmed nest would not be within 500 m of each other, which is also the same distance used to eliminate extra nests in a colony situation. I then used the 'Create Random Point' tool to randomly position an absence point within the donut-shaped area surrounding each confirmed nest location. In a strict sampling sense, these random absence points (as described below) represent pseudo-absence in that I did not visit the points and ground-truth or use Google Street View to verify the "absence" of a nest (Figure 3).

To increase confidence that the randomly generated pseudo-absence points were accurately representing an area without Monk Parakeets, I consulted the Monk Parakeet observation data from eBird. For each of the pseudo-absence points, I created three buffers sized at 100 m, 250 m, and 500 m as was done for the confirmed nest locations. My criteria for accepting a pseudo-absence point was no Monk Parakeet observations (individuals or flocks) within the 100 m buffer, ≤ 3 observations in the 250 m buffer, and ≤ 5 observations in the 500 m buffer. Pseudo-absence points were also rejected if they were generated in an area that obviously could not be a possible nesting location, such as a pond or the ocean.

Acquiring and processing landscape-level habitat data

To obtain landscape-level environmental data, I used the TCC and IMP data layers from the NLCD and the water feature data layers from the NHD as described earlier. The TCC layer quantifies the amount of dense/woody vegetation. The IMP layer essentially quantifies an amount of infrastructure (buildings, streets, parking lots, and various paved surfaces) that generally represents urbanization. Thus, this NLCD layer allowed me to quantify the overall amount of urbanization surrounding Monk Parakeet nests. The NHD allowed me to identify surface water features in proximity to the nest structures. Specifically, I determined the distance of the nearest surface water feature to each nest location and the type of surface water feature.

Once I created the buffered areas around each presence and absence location, I used the ‘Clip Raster’ tool in ArcGIS to clip out the raster imagery from each of the two NLCD layers. For each location, I created six clipped images, three buffered areas of the different radii for both the TCC layer and the IMP layer. Each of these clipped images was comprised of a certain number of 30 x 30 m pixels representing the percent cover of impervious surface and woody canopy. For example, a 100 m radius buffer is an area of 31,400 m^2 and thus about 35 30 x 30 m pixels. I extracted both the mean and the coefficient of variation (CV) for the set of pixels within each clipped image. The mean describes the average percentage of the impervious surface or tree canopy cover pixel values within the clipped area. The CV describes the relative heterogeneity of the pixel values within the clipped image, quantifying how discontinuous and varied (high CV) the impervious surface or tree canopy cover is within the buffers around each presence and absence location, or how continuous and uniform (low CV) either layer is. Note that in the Results, I present the CV values as the ratio of the SD to the mean (CV = SD/mean) rather than expressing the CV as a percentage as is sometimes done.

Some nest locations and absence points resulted in a buffered area where the TCC-mean or IMP-mean value was 0% (that is, no canopy cover or impervious surface within the buffered area). Because of this, a CV value could not be calculated for that buffer distance and thus those points were removed from subsequent regression modeling on TCC-CV and IMP-CV. Due to the removal of these points, sample sizes for single-factor regression analyses on TCC-CV and IMP-CV were smaller than those for TCC-mean and IMP-mean (See Statistical Analysis and Results).

To obtain the distance to nearest water source, I used the ‘Near’ tool in ArcGIS Pro to calculate the distance from each presence/absence location to the nearest NHD water feature. There are many water features available in the NHD that represent water that would not be accessible or potable to Monk Parakeets and thus these features were not used to get nearest distance values. From the NHD Flowline layer, I kept the Canal/Ditch and Stream/River features, removing features such as Pipeline, Underground Conduit, and Shoreline, as they are either underground and thus inaccessible to Monk Parakeets or they are jurisdictional boundaries. From the NHD Waterbody layer, I kept the Lake/Pond, Reservoir, and Swamp/Marsh features, removing features such as Estuaries and Ice Masses. From the NHD Area layer, I kept the Canal/Ditch, Flume, Inundation Area, Spillway, Stream/River, and Wash features, removing features such as Bridges, Dams, Ocean/Sea, and Submerged Stream. I used the largest buffer extent (500

m) as an upper limit for the distance-to-water variable, as any larger distance would not be scaled consistently with the other environmental variables. That is, when the measured distance was greater than 500 m, I replaced it with a value of 500 m. In other words, a value of 500 m indicates that a water feature was not present in the buffers.

Statistical Analysis

For all statistical analyses, I utilized the RStudio (v 1.3.1093) program to conduct multiple logistic regression and linear regression models (R Core Team 2020). The regressions were conducted as generalized linear models using the *glm()* function with either *family* = *binomial* and *link* = *logit* (for logistic regression) or *family* = *Gaussian* and *link* = *identity* (for linear regression). To investigate my first research question, single-factor models were constructed with the presence or absence of a Monk Parakeet nest as the response variable and either TCC-mean, TCC-CV, IMP-mean, IMP-CV, and distance to nearest surface water feature as predictor variables for each buffer size (100 m, 250 m, and 500 m) to examine the singular direct effect of each predictor variable on the presence of Monk Parakeet nests. The exception to this is the distance to nearest surface water feature predictor variable, as the distance to the nearest water source does not change between different buffer sizes, so only one single-factor model was constructed. The results from these logistic regressions provided β coefficients for each of the predictor variables. These coefficients indicate the effect of the predictor variable on the presence of Monk Parakeet nests. For example, a significant and positive β coefficient indicates that the given environmental variable (e.g., tree canopy cover) has a positive effect on Monk Parakeet nesting in that nests are more likely to occur as the variable becomes more common within the landscape (at scales of 100 m, 250 m, or 500 m radius circles).

In addition to these single-factor regression models, I constructed two sets of full models for each buffer size. The first set of these models examined the effect of each environmental variable on Monk Parakeet nesting when the other four variables are also included in a model. Each full model had a total of 5 predictor variables: TCC-mean, IMP-mean, Distance to nearest surface water feature, latitude, and longitude as main effects. Recall that the sample sizes for TCC-CV and IMP-CV were less than those for TCC-mean and IMP-mean, therefore I did not include either TCC-CV or IMP-CV in these full models. An alternative approach would have been to include TCC-CV and IMP-CV in the full models by removing all presence and absence locations that had 0% TCC or 0% IMP (as this would provide a balanced dataset). However, this approach would have greatly reduced sample sizes for the full regression models and omitted the potentially important influence of zero values for TCC-mean and IMP-mean, so I opted not to follow this approach.

The second set of full models included interactions between latitude and longitude and TCC-mean, IMP-mean, and the distance to nearest surface water feature, thus allowing me to address the second research question. Each full interaction model had a total of 11 predictor variables: (1) TCC-mean, (2) IMP-mean, (3) distance to nearest surface water feature, (4) latitude, and (5) longitude as main effects, and then each of the first three as interactions with latitude and longitude (i.e., 6 additional variables). A significant interaction term indicates that the effect of the environmental predictor variable on presence of Monk Parakeet nests depends on latitude or longitude.

Finally, I also tested for a pure direct effect of latitude and longitude on each of the five environmental variables measured within each buffer surrounding Monk Parakeet nests. These tests were conducted as simple linear regressions of latitude and longitude (as predictors) on TCC-mean, TCC-CV, IMP-mean, IMP-CV, and distance to nearest surface water feature as response variables. Again, the sample sizes for TCC-CV and IMP-CV were smaller than those for TCC-mean, IMP-mean, and distance to nearest surface water feature. Regressions were performed on presence locations (Monk Parakeet nests) separate from regressions on the absence locations (random points). For a given variable and buffer distance, when the regression on the presence locations was statistically significant ($P < 0.05$) I then examined the counterpart regression conducted on the absence locations. If this latter regression was non-significant or the β coefficient was opposite in sign (to the β for the presence locations) I deemed the significance of the regression on the presence locations to be real and not simply a reflection of an underlying latitudinal or longitudinal gradient in the environmental variable. The β coefficient and significance of the regression on the absence locations represents the strength of the underlying gradient regardless of Monk Parakeet nesting.

III. RESULTS

I identified 280 Monk Parakeet nest locations across the United States, with most nests located in Florida, New York, and Texas (Figure 2). Of these confirmed nest locations, 65 were found on utility poles (23% of total confirmed nests), 57 in electrical substations (20% of total), 38 nests in cellular phone towers (14% of total), 36 in light towers (13% of total), 32 in various species of trees (11% of total), 27 in transmission towers (10% of total), and the remaining nests were found in an assortment of anthropogenic structures.

The average TCC-mean values around these nests ranged from 4 – 9% across the three buffer sizes (Table 1). The maximum values for TCC-mean at confirmed nest locations ranged from 39 – 44%, while the minimum value for TCC-mean was 0% across all three buffer sizes (Table 1). Mean and maximum values for TCC-mean at the random points were typically greater than those at Monk Parakeet nests (Table 1, Figure 4). The distribution of TCC-mean values for all three buffered areas is massed on the left indicating many Monk Parakeet nests were at the center of landscapes with TCC-mean values that were 0% or very low with only a few in landscapes where TCC-mean was ≥ 25% (Figure 4).

The average IMP-mean values for Monk Parakeet nests ranged from 44 – 51%, which was only slightly greater than the IMP-mean values for the random points (Table 1, Figure 5). The maximum values for confirmed nest locations ranged from 89 – 93%, similar to the maximums of the random points (Table 1, Figure 5). The distributions of IMP-mean values for Monk Parakeet nests were somewhat different from those for random points particularly at the smallest buffer distance of 100 m (Figure 5).

The average TCC-CV values for Monk Parakeet nests ranged from 2.5 – 3 across all three buffer sizes, and the maximum TCC-CV values for Monk Parakeet nests ranged from 5 – 25 (Table 1, Figure 6). Both the mean and maximum values of TCC-CV values for Monk Parakeet nests tended to be similar to those calculated for the random points (Table 1, Figure 6).

The average IMP-CV values for the Monk Parakeet nests ranged from 0.5 – 0.7 across all three buffer sizes, similar to those found at the random points (Table 1, Figure 7). The maximum values ranged from 2 – 4, which were lower than those of the random points (Table 1, Figure 7).

As stated earlier, I had to remove some of the locations because the CV values could not be calculated (see Methods). For the TCC-CV predictor variable, I removed 160 points at 100 m (85 presence locations, 75 absence locations) giving me a final sample size of 400 points. From the 250 m buffers, I removed 50 points (26 presence, 24 absence), giving a final sample size of 510, and from the 500 m buffers, I removed 16 points (8 presence, 8 absence), giving a final sample size of 544. For the IMP-CV predictor variable, I removed 20 points at 100 m (1 presence, 19 absence) giving me a final sample size of 540 points. I removed 6 absence points at 250 m, giving me a final sample size of 554, and I removed 3 absence points at 500 m, giving me a final sample size of 557.

The average distance to nearest surface water feature around both the confirmed nest locations and the pseudo-absence locations was 281 m (Table 1). For both the confirmed nest locations and the pseudo-absence locations, the maximum distance was 500 m, while the minimum distance was 0 m (Table 1, Figure 8).

Tree Canopy Cover

TCC-mean had a negative effect on Monk Parakeet nesting as indicated by statistically significant ($P < 0.01$) negative β coefficients in the logistic regression models (Table 2). Moreover, this negative effect was observed at all three buffer sizes in both the single-factor models and the full models that did not include interactions, although it was strongest at the smallest buffer size (100 m) where the β coefficients had their greatest magnitude (Table 2). The negative effect of TCC was also revealed by a direct comparison of the mean value of TCC-mean in the presence versus absence locations, over all three buffer sizes. Locations with Monk Parakeet nests tended to have less canopy cover on average and lower maximum values compared to random points (Table 1, Figure 4). The main effect from the full models with interactions were non-significant, and the interactions between TCC-mean and latitude and longitude were also non-significant, indicating that the negative effect of TCC-mean on Monk Parakeet nesting does not depend on geographic location (Table 2, Table 6).

TCC-CV had a positive effect on Monk Parakeet nesting as indicated by a statistically significant ($P < 0.01$) positive β coefficient in the single-factor logistic regression models at 100 m and 250 m (Table 3). This positive effect was strongest at the smallest buffer size (100 m) where the β coefficients had its greatest magnitude. At the 500 m distances, TCC-CV had no significant effect on the presence of Monk Parakeets nests (Table 3).

Percent Developed Imperviousness

IMP-mean had a positive effect on Monk Parakeet nesting as shown by a statistically significant ($P < 0.01$) positive β coefficient in both the single-factor model and the full logistic regression model without interactions within the 100 m buffer distances (Table 4). At 250 m and 500 m, the single-factor models for both distances indicated that IMP-mean had a statistically significant (250 m: $P < 0.01$, 500 m: $P < 0.05$) positive effect on Monk Parakeet nesting, but the effect of IMP-mean was not significant in the full models without interactions at 250 and 500 m (Table 4). The main effect from the full models with interactions were non-significant, and the interactions between IMP-mean and latitude and longitude were also non-significant, indicating that the positive effect of IMP-mean on Monk Parakeet nesting does not depend on geographic location (Table 4, Table 6).

IMP-CV had a negative effect on Monk Parakeet nesting as indicated by a statistically significant ($P < 0.05$) negative β coefficient in the single-factor logistic regression model at all three buffered distances (Table 3). The magnitudes of these effects were similar across all three buffered distances but was greatest at the 250 m buffer distance (Table 3).

Distance to nearest surface water feature

In the single-factor models, the distance to nearest surface water feature did not have a significant effect on Monk Parakeet nesting at any of the three buffer distances (Table 5). On average, Monk Parakeet nests were no closer or further from a surface water feature than were the random points (Table 1, Figure 8). However, the full regression model without interactions revealed a significantly ($P < 0.05$) negative β coefficient at 100 m buffer distance (Table 5). The β coefficients for distance to nearest surface water feature were also not significant at the 250 m and 500 m buffer distances in the full models without interactions (Table 5). The main effect from the full models with interactions were non-significant, and the interactions between the distance to nearest surface water feature and latitude and longitude were also non-significant, indicating that the negative effect of the distance to nearest surface water feature on Monk Parakeet nesting at the 100 m buffer distance does not depend on geographic location (Table 5, Table 6).

Direct Effects of Latitude and Longitude

For this analysis, 26 pairs of single-factor linear regressions were examined, one pair for each of the five environmental variables at each of three buffer sizes and regressing against either latitude or longitude, with the pairing based on presence/absence of Monk Parakeet nests. Of the 26 pairs, only nine revealed a significant β coefficient ($P < 0.05$) from the regressions on confirmed Monk Parakeet nest locations combined with a counterpart regression on the absence locations that had either a non-significant or opposite-in-sign β coefficient (Table 7). Of these nine pairs, two involved TCC-mean and had presence locations with positive β coefficients, five involved TCC-CV and had negative β coefficients, and the last two involved IMP-CV and also had negative β coefficients. TCC-mean of the 100 m buffers increased with increasing latitude (i.e., in a northward direction) and TCC-mean of the 250 m buffers increased with increasing longitude (i.e., in an eastward direction) [*Note: longitude is represented by negative values*] (Table 7). The heterogeneity of tree canopy cover in the buffers surrounding Monk Parakeet nests decreased with increasing latitude and increasing longitude. Given that TCC-mean is inversely correlated with TCC-CV at all three buffer distances ($r = -0.65$ at 100 m, $r = -0.51$ at 250 m, and $r = -0.48$ at 500 m) latitudinal and longitudinal gradients of TCC-mean and TCC-CV cannot be completely separated (see Discussion).

IMP-CV of the 250 and 500 m buffers decreased with increasing latitude (Table 7) indicating less heterogeneity in impervious surface cover at more northerly latitudes. However, it should be noted that despite the statistical significance of these β coefficients, all these regressions had relatively low R-squared values between 0.015 – 0.095, which indicates only a small portion of the variation in the environmental variables is accounted for by these regressions (Table 7).

Lastly, it is also important to point out that the *direct effects* of latitude and longitude on Monk Parakeet presence/absence in the logistic regression models (with and without interactions) at each buffer distance were non-significant. This is not biologically meaningful but simply reflects my study design. Each nest location (presence point) was used to pinpoint a pseudo-absence random point within 2 km, hence the mean latitude (and mean longitude) of nest locations and random points were not different.

IV. DISCUSSION

Monk Parakeets are resourceful when it comes to building nests on a wide variety of structures, both natural and anthropogenic, and this likely has facilitated establishment of populations in urban areas (Minor et al. 2012, Burgio et al. 2014, Reed et al. 2014). There is substantial variability in the structures used for nest-building, including height above ground, construction materials used, and overall shape. Indeed, Monk Parakeets in urban environments seem to not even require trees or much woody vegetation of any type upon which to build their nests. A plot of predicted probability of Monk Parakeet nesting versus tree canopy cover clearly shows a negative effect of canopy cover (Figure 9). This suggests that Monk Parakeet nests are more likely to be present in areas with low canopy cover and in areas that have high heterogeneity of canopy cover. Interestingly, out of the confirmed Monk Parakeet nest locations, 26 of the nests were in an area without any canopy cover (woody vegetation) within 250 m of the nest, and of those, 8 nests did not have any canopy cover within 500 m of the nest (Figure 4). Perhaps it is possible that Monk Parakeets can fly further than 500 m away from their nest location to harvest woody vegetation to construct their nests; to my knowledge no studies have examined the daily routes and pathways utilized by Monk Parakeets, especially in their introduced locations. It is also possible that sufficient nesting material was available within 500 m (or even closer), but because the Tree Canopy Cover layer is somewhat coarse-grained at 30 x 30 m pixel resolution, there might be insufficient woody vegetation to produce a visible effect to the layer, but enough that the Monk Parakeets would be able to harvest and construct a nest.

The avoidance by Monk Parakeets of areas with a high percentage of canopy cover is also reflected in their response to variation in canopy cover. In general, as the heterogeneity of canopy cover increased, the chances of a Monk Parakeet nest being present also increased (Figure 9). This effect may, in part, be due to TCC-mean and TCC-CV being inversely correlated (r = -0.65, -0.51, and -0.48 respectively for 100, 250, and 500 m buffers). Nonetheless, there is likely also a direct effect of canopy cover variation. The tree canopy cover conditions around Monk Parakeet nesting locations in the United States appear to be similar to those in their native habitat. In their native ranges, Monk Parakeets nest in open savanna areas with scattered tall trees, which would be described as overall low canopy cover with high canopy cover variation around the nest location (Burger and Gochfeld 2005, Bucher and Aramburú 2014). But instead of nesting amongst scattered woody areas, Monk Parakeets are more frequently found to nest in anthropogenic structures. While they use these structures instead of trees to nest in, they still appear to require woody vegetation nearby, either to harvest nest materials from or to use as perches throughout the day. In fact, the immediate area surrounding some of the more common anthropogenic nesting structures, such as electrical substations or transmission towers, is often altered by utility workers to be free of potential obstructions or hazards. Further, these areas are maintained to provide ease of access for humans working on the electrical infrastructure. This can result in large swaths of short or mowed grasses around the structures, to provide ease-of-access for people working on utility poles and transmission towers. Pockets of trees are also often used to hide structures like electrical substations from view for aesthetic reasons (USDA 2001). These occasional stands of trees with lots of grassy areas around a sturdy nest structure would appear physically similar to their native habitat, which would presumably make them more appealing to Monk Parakeets.

However, unlike those Monk Parakeets in their home ranges, introduced Monk Parakeets are often found in urbanized areas, not out in open savannas or grasslands. The probability of Monk Parakeet nesting increased as the percent cover of impervious surface or degree of urbanization in the landscape increased (Figure 9). The average percent of impervious surface cover was greater in the confirmed nest sites than the absence sites, even though the absence sites were constrained to be 2 km from the nest location (Table 1, Figure 5). This shows that even within an urbanized or metropolitan area, Monk Parakeets seem to be more associated with areas that have the greatest cover of impervious surface. Because Monk Parakeets build their nests more commonly on anthropogenic structures (at least in the United States), a greater degree of urbanization within a landscape would entail a greater number of potential nesting locations or structures for Monk Parakeets to utilize (Reed et al. 2014).

The overall association of Monk Parakeets with urbanization might also be partly explained by point of introduction (or release). The popularity of some exotic bird species can lead to multiple waves of introduction into a new environment, boosting the base populations of these bird species compared to other introduced taxa, and although Monk Parakeets are reproducing in many cities within the United States, the existing breeding populations might be bolstered by release of captive birds. These waves of release can help the population either initially survive while maintaining enough breeding individuals, or periodic releases could just increase the size of an already established population (Møller 2009, Sol et al. 2017). Such releases would most commonly occur in urban (i.e., residential) areas where more people are likely to buy and release unwanted pets. Some states in the United States have a ban on the selling and ownership of Monk Parakeets, which has likely prevented the initial introduction of these birds in those states or reduced the number of releases, but this would primarily affect the legal bird and pet trades. So, by consistently remaining in urban areas, Monk Parakeets should have a better opportunity to find both other conspecifics and strong structures to build a nest on.

However, the probability of Monk Parakeet nesting actually decreases with an increase in the heterogeneity of impervious surfaces in the surrounding landscape (Figure 9). This negative effect may partly be due to the direct positive effect of impervious surface given that IMP-CV and IMP-mean were inversely correlated (r = -0.72, -0.64, and -0.65 at 100, 250, and 500 m respectively). Nonetheless, there is probably also a direct negative effect of heterogeneity in impervious surface cover. Monk Parakeets might avoid locations with substantial spatial variation of percent impervious surfaces. Areas with more impervious surfaces, and more consistent imperviousness, would probably have more anthropogenic nesting structures to build on, rather than areas that might only be partially developed, or adjacent to some undesirable habitat. Such variation could represent edges between human-modified areas (e.g., retail and commercial plots, high-density housing, parking lots and streets) and areas that are modified but without much pavement (e.g., city and state parks, ornamental lawns, low-density housing). Areas in the latter category might have fewer of the anthropogenic structures, such as electrical substations and infrastructure, that are more common in highly urbanized areas. As one moves out into the more rural areas, with lower percent impervious surfaces, there would be fewer anthropogenic structures to build upon, as well as a smaller chance to find other

Monk Parakeets. Without the presence of these structures, finding a suitable nesting structure might become more difficult. So even within an urban environment, Monk Parakeets appear to be more associated with areas that have a higher percentage of impervious surface.

In addition to the nesting structures, urban areas have a variety of food sources that are both plentiful and easy to access. In their natural habitat, Monk Parakeets primarily fed on seeds and fruits of the native grasses and trees. When agricultural production in South America began to increase and *Eucalyptus* trees were introduced, Monk Parakeets began moving closer to rural human settlements. In addition to feeding on available crops and fruits, they would feed on the seeds from shorter grasses found in nearby livestock-grazed fields, as these grasses have easier-to-access seeds compared to the taller native grasses, allowing for them to get more food with less effort (Bucher and Aramburú 2014). While there are obviously not large tracts of agricultural plots or livestock-grazed fields in the non-native urban areas, there are instead manicured lawns, athletic fields, and highway green areas that can provide plentiful food resources for Monk Parakeets. Birdseed from bird feeders has been identified as a staple food source for Monk Parakeets, in one study making up almost of a quarter of their observed diet (South and Pruett-Jones 2000, Minor et al. 2012, Pruett-Jones et al. 2012). Some populations of Monk Parakeets have been observed exclusively consuming birdseed from feeders, making up the entirety of their observed diet from local bird feeders, again showing the necessity of anthropogenic sources of food that would be present only in urban environments, thus the continued positive association with high impervious surfaces and urbanization (South and Pruett-Jones 2000, Uehling et al. 2019).

Availability of water sources appeared to have very little effect on the presence of Monk Parakeets. Because water is needed for daily survival, it makes sense for nests and colonies to be located near water, thus it is surprising that access to water had so little effect in the regression models. However, the database used for the water-distance variable (NHD) only includes major hydrogeologic features that are more permanent water sources such as rivers, ponds, and lakes. Smaller, more ephemeral sources of water such as birdbaths or backyard swimming pools are not included in the NHD GIS layers. In addition to these sources, small indents in sidewalks, roads, and other impervious surfaces that might pool water after a rainstorm or heavy sprinkler usage are thought to be important to Monk Parakeets (Reed et al. 2014). An area with more impervious surfaces would also have more locations for water to pool and have a larger capacity to hold this pooled water This could be another facet of the positive effects of impervious surfaces and urbanization on the presence of Monk Parakeet nests. Alternatively, since I truncated the distance to nearest surface water feature variable to 500 m, it is possible that Monk Parakeets can daily fly greater than 500 m when necessary to obtain water from a permanent source (Figure 8).

As previously mentioned, Monk Parakeets are adaptable when it comes nest construction, but this resourcefulness is also shown by the wide variety of climates that Monk Parakeets can tolerate (Avery et al. 2012, Uehling et al. 2019, Burgio et al. 2020). While the native range is the semiarid savanna of South America, where the climate is temperate and annual mean temperatures range from around 14°C - 20°C, there are established non-native populations of Monk Parakeets in a wide range of climates, including some areas that have much colder temperatures than found in their native range

(Bucher and Aramburú 2014). One of the earliest confirmed populations in the United States was in Chicago, IL, where winter minimum daily temperatures are well below freezing, much colder than the winter climate in their native range (Davis et al. 2014). There are also Monk Parakeet populations in several cities in Texas, where summer temperatures can reach over 38°C for multiple days in a row. Due to the physical structure of their nests, internal temperature does not fluctuate as much as ambient temperature, allowing Monk Parakeets to spend less energy on thermoregulation thus increasing their survival chances during the most extreme winter weather (Viana et al. 2016). Therefore, it was interesting that I did not find a significant effect of either latitude or longitude on the relationship between any of the five environmental variables and the presence of Monk Parakeet nests. I initially believed that there might be some differences in nest construction to accommodate for the range of temperatures based on where they were in the country, and that those differences might be reflected in associated habitat around the nest site location, but the latitude and longitude interaction terms in the full multiple logistic regression models were all non-significant. This indicates that for each of the environmental variables, the difference between nest locations and random points does not depend on latitude or longitude.

However, there was latitudinal and longitudinal-based variation in some of the five environmental variables that characterized landscapes surrounding Monk Parakeet nests (Table 7). This variation mostly involved either the mean amount or heterogeneity of tree canopy cover, rather than impervious surface cover. Monk Parakeet nests at more northerly and easterly locations in the United States tended to be in landscapes with less heterogeneity in tree canopy cover than the landscapes occupied by Monk Parakeets at locations further south and west in the United States. This pattern might also entail northeastern locations having a greater overall amount of tree canopy cover as TCC-mean and TCC-CV were negatively correlated, although TCC-mean was significantly related to latitude only at the 100 m buffer distance and longitude only at the 250 m buffer distance. Perhaps, populations in the more northern and eastern areas of the United States like the Chicago or New York metropolitan areas require greater availability of woody vegetation (i.e., nesting material) in order to construct and maintain larger nests with thicker "walls" to insulate against cold winter weather.

There was also a latitudinal gradient in heterogeneity of impervious surface cover surrounding Monk Parakeet nests. Heterogeneity was greater at more northerly locations, although only for the 250 and 500 m buffered landscapes, not the 100 m landscapes. Again, given a negative correlation between IMP-mean and IMP-CV, greater heterogeneity entails a lower overall mean amount of impervious surface cover. Monk Parakeets populations in the more northern and eastern areas of the United States seem to nest in locations that have less impervious surface (concrete, asphalt pavement, and buildings) which also likely allows for greater tree cover. But, without more detailed information on the construction of nests in these areas, and accounting for the small r-squared values from the regressions, the relevance of these geographic gradients to Monk Parakeet nest site selection and population establishment is difficult to exactly decipher (Table 7). There might be some behavioral differences in the Monk Parakeet's nest building tactics in different parts of the country, but that is beyond the scope of my study.

V. CONCLUSION

The results of my study demonstrate that Monk Parakeets are positively associated with urban environments. It seems unlikely that they will expand their range to more rural areas and become an agricultural pest like they are in their native habitat. While Monk Parakeets are known as an agricultural pest species in their native range due to crop damage, they do not appear to pose that kind of threat in the United States, although they can be a nuisance depending on where they build their nests, primarily through damaging electrical equipment, but they do also cause noise complaints with their loud and distinctive calls, and they can potentially carry some avian diseases such as Psittacosis.

To date the species is limited to urban areas and established populations have not expanded to the countryside surrounding any urban area. Even in their native range, where Monk Parakeets would build their nests in the trees scattered throughout the savanna, the increased human activity and agriculture prompted Monk Parakeets to move closer to human settlements due to the higher quality and availability of nesting structures, primarily introduced *Eucalyptus* trees and anthropogenic structures (Navarro et al. 1992). While the United States has natural non-urban habitat that is similar to their native range (grassland with scattered trees), colonizing these countryside environments from the point of introduction or release (in cities) could be difficult for Monk Parakeets. Observational studies have shown that Monk Parakeets in their native range have a relatively short dispersal distance of around 2 km, although genetic studies have revealed that Monk Parakeets in non-native regions are capable of long-distance dispersal around 100 km (Bucher et al. 1990, Da Silva et al. 2010). Thus, it is possible that Monk

Parakeets disperse further distances in the non-native range than in their native range which allows them to reach new metropolitan areas without colonizing the intervening countryside.

However, the conclusions drawn from my study suggest that for now they are more likely to remain in urban areas rather than dispersing out into non-urban areas, where there are less likely to be reliable anthropogenic structures for nests as well as a lower encounter rate for other Monk Parakeets. We do not have a good estimate of what the carrying capacity might be for Monk Parakeets in an urban environment, and it could be that once they have saturated their urban area, they will begin dispersing out into non-urban areas, and become the agricultural pests that they were originally feared to. The introduced population in Hyde Park, Chicago, IL, is one of the oldest and most consistently researched Monk Parakeet populations. A recent study examined why the population and colonies in the Hyde Park area had started to slowly decline, even though the overall Chicago population has continued to steadily increase. It seems that they may have reached a density and population limit within the area, and that they are now dispersing themselves to further parts of the city, spreading out into smaller colonies (Pruett-Jones et al. 2012). However, this kind of expansion is difficult to track without a dedicated and interested party or organization, as most governmental agencies don't track and record non-native or introduced species unless they are causing a significant problem.

While Monk Parakeets don't appear to be truly invasive, as for now they are primarily only found in urban areas, other introduced species might not be as constrained. Once such introduced species and another member of the Psittacidae family, the Rose-ringed parakeet (*Psittacula krameri*) is another bird that has adapted to the urban environment similarly to Monk Parakeets. However, unlike the Monk Parakeets, they are secondary-cavity nesters, leading them into direct competition with native species for available cavities and food resources, and often out-competing them, which has resulted in their generally accepted status as an invasive species in parts of Europe (Brochier et al. 2010). By better understanding the habitat associations of introduced birds like these, it should become easier to track their population growth and better identify potential invasion locations. But based on the available data, the conclusions drawn from my study suggest that the establishment and growth of Monk Parakeets is facilitated by urban environments, and that they clearly rely on and have likely adapted to living in urban environments and will continue to do so into the future.

VI. TABLES

Table 1. The mean, minimum, and maximum values for each landscape variable at all three buffer sizes, separated by whether the data are for the confirmed Monk Parakeet (*Myiopsitta monachus*) nest locations or the pseudo-absence locations. Values for TCC-mean and IMP-mean are shown as percent cover. Values for TCC-CV and IMP-CV are shown as SD/mean and hence are unitless. Values for Distance to nearest surface water feature are shown as meters. See text for further details.

Variable	Buffer size	Presence/Absence	Mean	Minimum	Maximum
TCC-mean	100 m	Presence	4.78	0	44.22
	250 m		7.03	0	39.13
	500 m		9.13	0	42.63
	100 m	Absence	13.37	0	93.92
	250 m		12.96	0	82.48
	500 m		12.71	0	74.56
TCC-CV	100 m	Presence	2.51	0.31	5.29
	250 m		3.09	0.59	13.12
	500 m		2.98	0.55	24.29
	100 m	Absence	1.66	0.03	5.29
	250 m		2.62	0.15	13.12
	500 m		2.81	0.20	26.08
IMP-mean	100 m	Presence	51.27	0	93.31
	250 m		48.18	2.26	90.14
	500 m		44.80	1.78	89.08
	100 m	Absence	41.20	0	95.67
	250 m		41.14	0	92.25
	500 m		40.54	0	89.86
IMP-CV	100 m	Presence	0.54	0.05	2.34
	250 m		0.64	0.08	3.18
	500 m		0.74	0.10	4.42
	100 m	Absence	0.64	0.05	4.90
	250 m		0.84	0.08	10.17
	500 m		0.89	0.11	10.33
Water Dist.	---	Presence	281.26	0	500
	---	Absence	281.87	0	500

Table 2. The effect of mean tree canopy cover (TCC-mean) on the presence/absence of Monk Parakeet (*Myiopsitta monachus*) nests in landscapes of three buffer sizes. At each buffer size, the effect was analyzed in three separate logistic regression models: single-factor model, full model without interactions, and full model with latitude and longitude interactions. See text for further details.

Model	Buffer size	β	β (SE)	*P*
Single factor	100 m	**-0.051**	0.009	<**0.001**
Full model w/o interactions		**-0.046**	0.010	<**0.001**
Full model with interactions		-0.118	0.105	0.262
Single factor	250 m	**-0.039**	0.008	<**0.001**
Full model w/o interactions		**-0.034**	0.009	<**0.001**
Full model with interactions		0.067	0.135	0.623
Single factor	500 m	**-0.025**	0.008	<**0.001**
Full model w/o interactions		**-0.022**	0.009	**0.012**
Full model with interactions		0.094	0.127	0.459

Table 3. The effect of the coefficient of variation of tree canopy cover (TCC-CV) and impervious surface (IMP-CV) on the presence/absence of Monk Parakeet (*Myiopsitta monachus*) nests in landscapes of three buffer sizes. At each buffer size, the effect was analyzed as a single-factor model. See text for further details.

Variable	Buffer size	β	β (SE)	*P*
TCC-CV	100 m	**0.503**	0.085	**<0.001**
	250 m	**0.068**	0.034	**0.049**
	500 m	0.018	0.029	0.521
IMP-CV	100 m	**-0.366**	0.173	**0.034**
	250 m	**-0.381**	0.142	**0.007**
	500 m	**-0.259**	0.126	**0.040**

Table 4. The effect of mean percent impervious surface (IMP-mean) on the presence/absence of Monk Parakeet (*Myiopsitta monachus*) nests in landscapes of three buffer sizes. At each buffer size, the effect was analyzed in three separate logistic regression models: single-factor model, full model without interactions, and full model with latitude and longitude interactions. See text for further details.

Model	Buffer size	β	β (SE)	*P*
Single factor	100 m	**0.018**	0.004	**<0.001**
Full model w/o interactions		**0.010**	0.005	**0.027**
Full model with interactions		-0.004	0.061	0.952
Single factor	250 m	**0.015**	0.004	**<0.001**
Full model w/o interactions		0.010	0.005	0.059
Full model with interactions		0.017	0.069	0.812
Single factor	500 m	**0.011**	0.004	**0.012**
Full model w/o interactions		0.008	0.006	0.175
Full model with interactions		0.047	0.075	0.531

Table 5. The effect of the distance to nearest surface water feature on the presence/absence of Monk Parakeet (*Myiopsitta monachus*) nests in landscapes of three buffer sizes. Given that distance to water does not change with buffer size, there is only one single-factor model. Therefore, at each buffer size, there were three separate logistic regression models: the single-factor model, a full model that included without interactions, and a full model with latitude and longitude interactions. See text for further details.

Model	Buffer size	β	β (SE)	*P*
Single factor	—	<0.001	0.001	0.968
Full model w/o interactions	100 m	**-0.001**	0.001	**0.019**
Full model with interactions		-0.002	0.007	0.794
Full model w/o interactions	250 m	-0.001	0.001	0.056
Full model with interactions		-0.001	0.007	0.833
Full model w/o interactions	500 m	-0.001	0.001	0.232
Full model with interactions		-0.002	0.007	0.792

Interactions	100 m			250 m			500 m		
	β	β (SE)	P	β	β (SE)	P	β	β (SE)	P
TCC Mean: Latitude	0.001	0.002	0.471	-0.001	0.002	0.655	-0.002	0.002	0.344
TCC Mean: Longitude	<0.001	0.001	0.695	0.001	0.001	0.415	0.001	0.001	0.511
IMP Mean: Latitude	<0.001	0.001	0.745	-0.001	0.001	0.440	-0.002	0.001	0.209
IMP Mean: Longitude	<0.001	<0.001	0.512	<0.001	0.001	0.583	<0.001	0.001	0.807
Water Distance: Latitude	<0.001	<0.001	0.255	<0.001	<0.001	0.309	<0.001	<0.001	0.409
Water Distance: Longitude	<0.001	<0.001	0.365	<0.001	<0.001	0.414	<0.001	<0.001	0.402

Table 6. The interaction terms from the multiple linear regression full models testing for interactions between either latitude or longitude on the three environmental variables (TCC-mean, IMP-mean, and distance to nearest surface water feature) across all three buffer sizes. See text for further details.

Table 7. The effect of either latitude or longitude on the five environmental variables (TCC-mean, TCC-CV, IMP-mean, IMP-CV, and distance to nearest surface water feature) across all three buffer sizes (distance to nearest surface water feature yielded only two pairs, as the data is the same at all three buffer sizes). At each buffer size, the effect was analyzed in a linear regression model. Of the 26 pairs of regressions conducted, table only gives results for those in which the regression on the presence locations (Monk Parakeet nests) was significant (*P* < 0.05) and the counterpart regression on the absence locations was non-significant or had a β coefficient opposite in sign[1]. See text for further details.

Environmental variable	Buffer size	Predictor	Presence			Absence		
			β	β (SE)	*P*	β	β (SE)	*P*
TCC-mean	100 m	Latitude	**0.195**	0.077	**0.012**	-0.056	0.200	0.780
	250 m	Longitude	**0.091**	0.043	**0.037**	-0.205	0.093	0.028
TCC-CV	100 m	Latitude	**-0.036**	0.016	**0.023**	-0.002	0.014	0.887
	250 m	Latitude	**-0.061**	0.028	**0.032**	-0.002	0.028	0.935
	100 m	Longitude	**-0.033**	0.009	**<0.001**	0.016	0.007	0.022
	250 m	Longitude	**-0.077**	0.015	**<0.001**	-0.005	0.016	0.729
	500 m	Longitude	**-0.062**	0.017	**<0.001**	-0.021	0.017	0.225
IMP-CV	250 m	Latitude	**-0.015**	0.004	**0.001**	-0.007	0.011	0.517
	500 m	Latitude	**-0.014**	0.006	**0.012**	-0.015	0.011	0.154

[1] Despite the statistical significance of the β coefficients, all these regressions had relatively low R^2 values between 0.015 – 0.095.

VII. FIGURES

Figure 1. A Monk Parakeet (*Myiopsitta monachus*) in a nest constructed on a utility pole (Photo credit: Andrew Lankes)

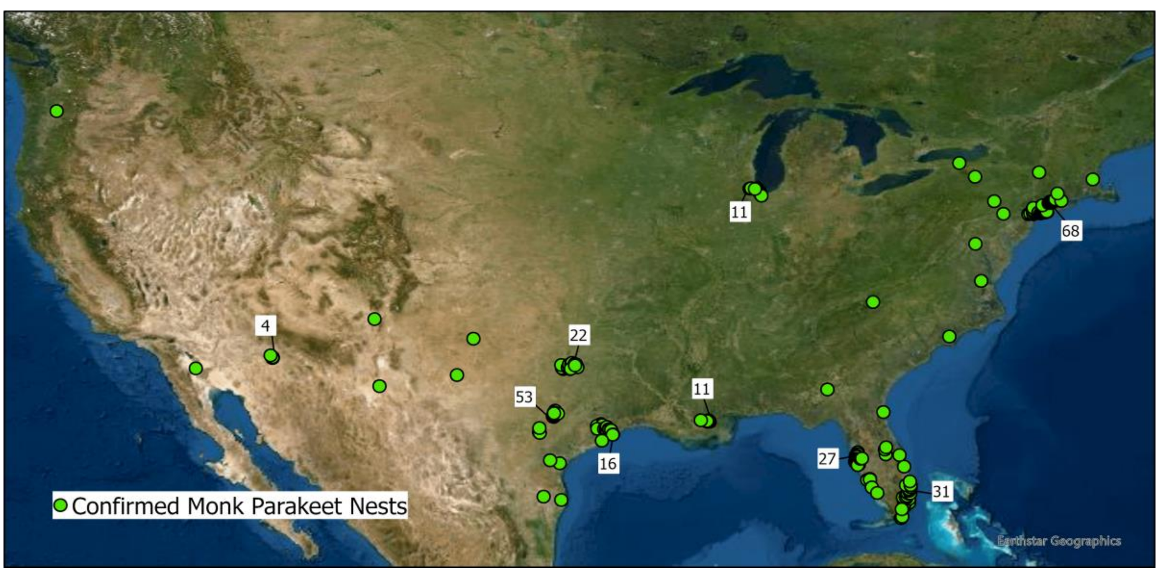

Figure 2. Confirmed Monk Parakeet (*Myiopsitta monachus*) nest locations in the continental United States (n = 280). Due to the number of nests in some metropolitan areas, the number of nests has been added to display nests more accurately across the United States.

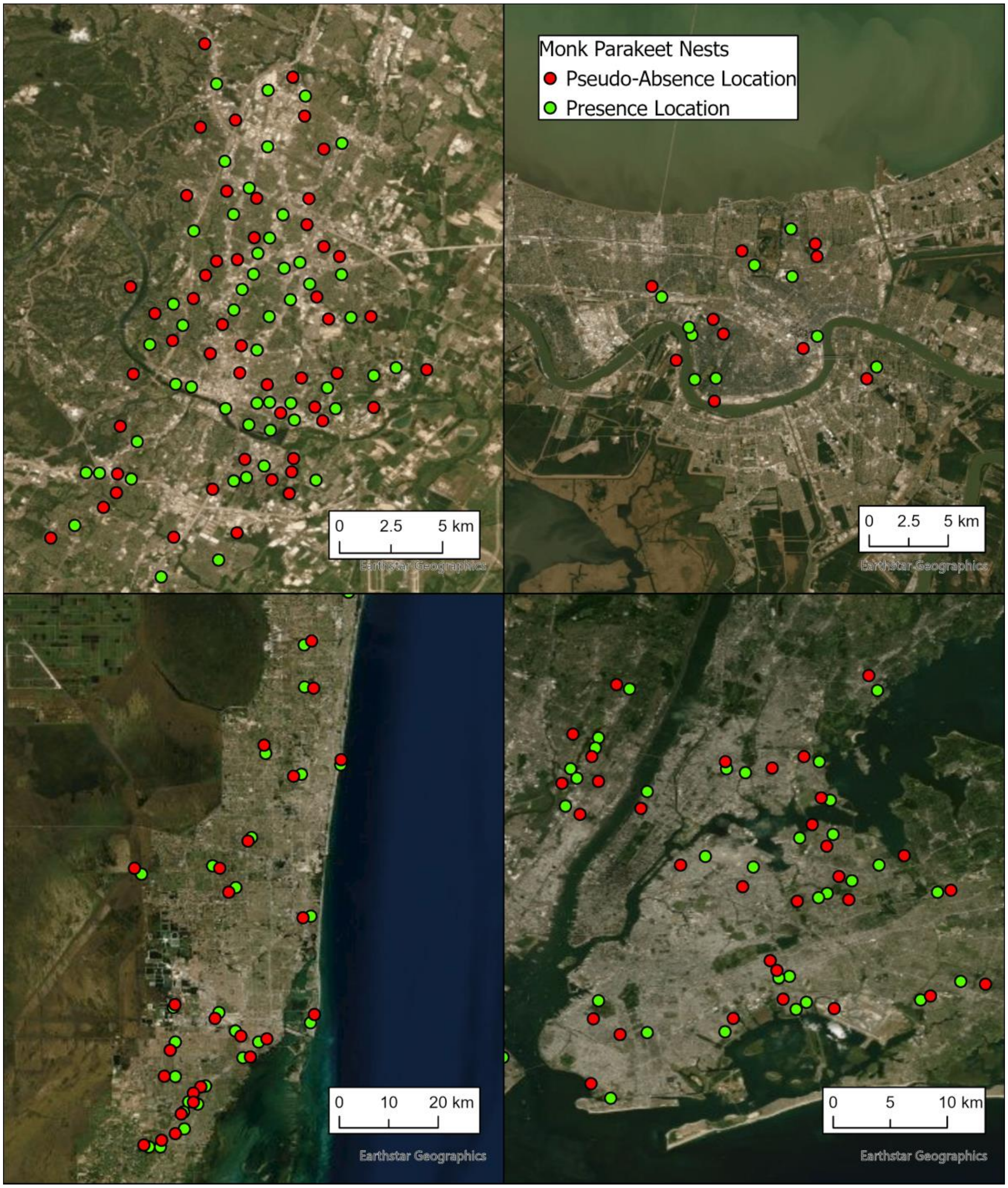

Figure 3. Spatial locations of confirmed Monk Parakeet (*Myiopsitta monachus*) nests and pseudo-absence points in Austin, Texas (top left), New Orleans, Louisiana (top right), Miami, Florida (bottom left), and New York City, New York (bottom right).

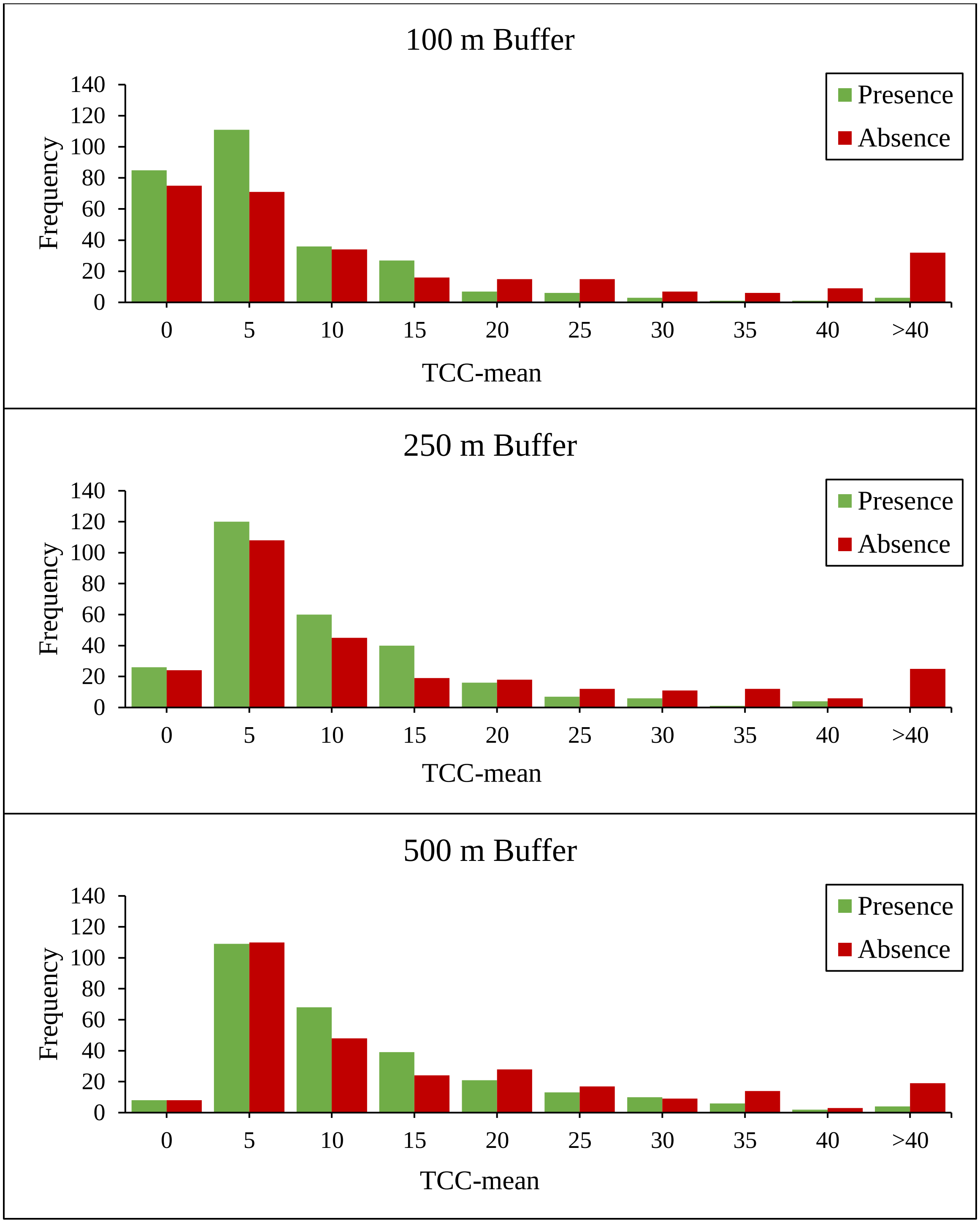

Figure 4. Frequency of mean tree canopy cover (TCC-mean) values for the Monk Parakeet (*Myiopsitta monachus*) presence and pseudo-absence locations across all three buffered distances.

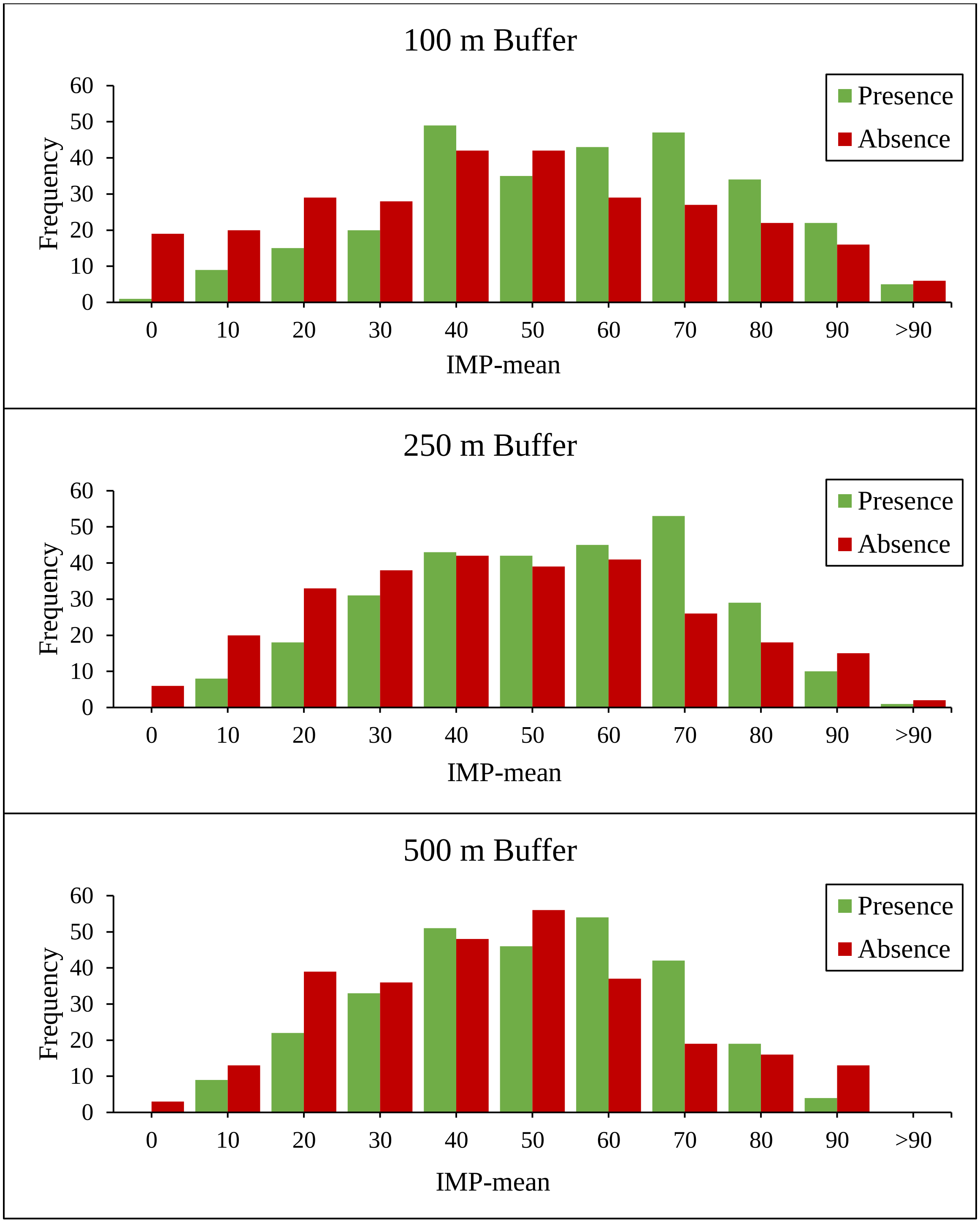

Figure 5. Frequency of mean percent impervious surface (IMP-mean) values for the Monk Parakeet (*Myiopsitta monachus*) presence and pseudo-absence locations across all three buffered distances.

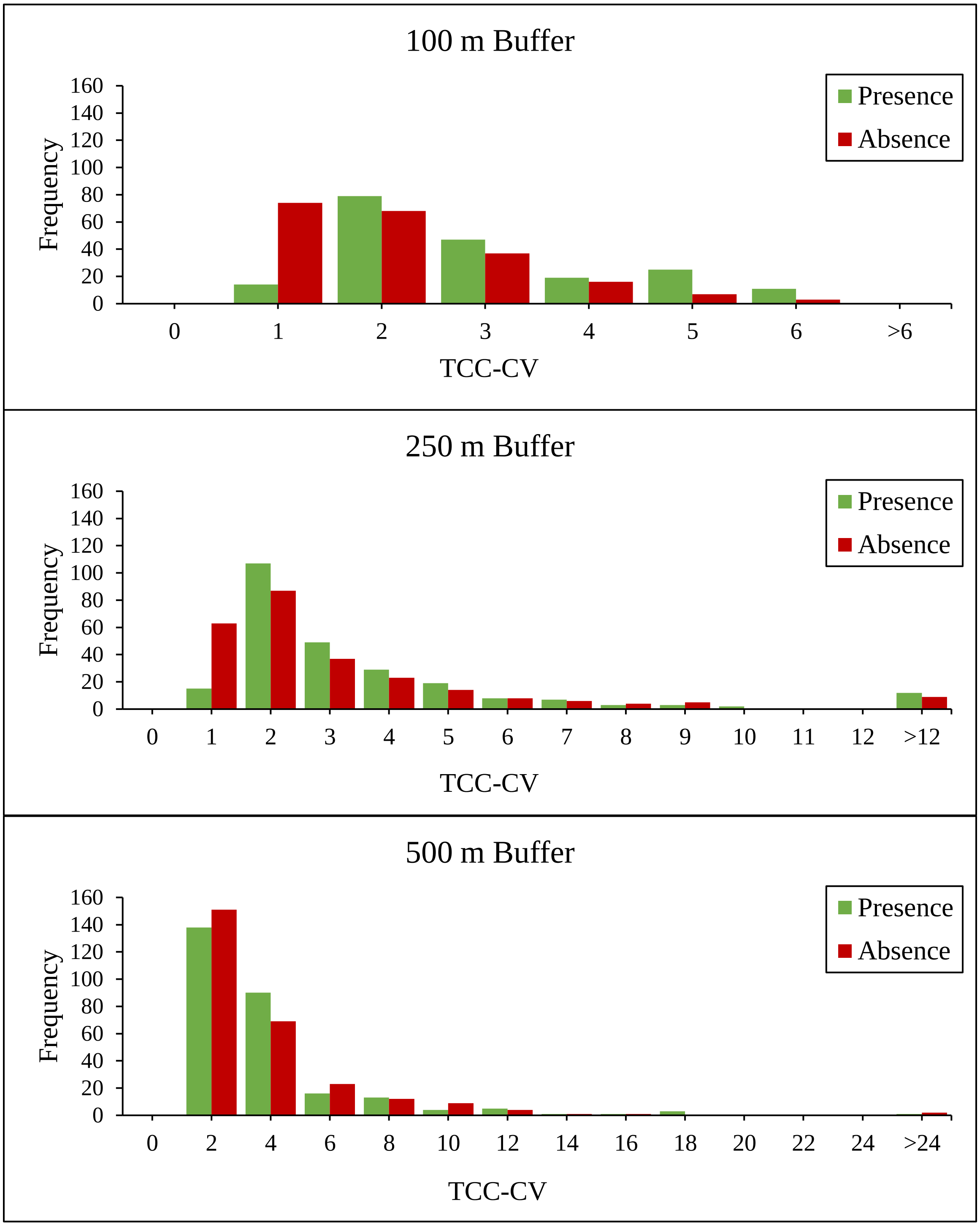

Figure 6. Frequency of the coefficient of variation of tree canopy cover (TCC-CV) values for the Monk Parakeet (*Myiopsitta monachus*) presence and pseudo-absence locations across all three buffered distances. Because CV is not defined when the mean is 0, some of the observations had to be removed, resulting in a smaller sample size compared to TCC-mean (100 m, n = 400; 250 m, n = 510; 500 m, n = 544).

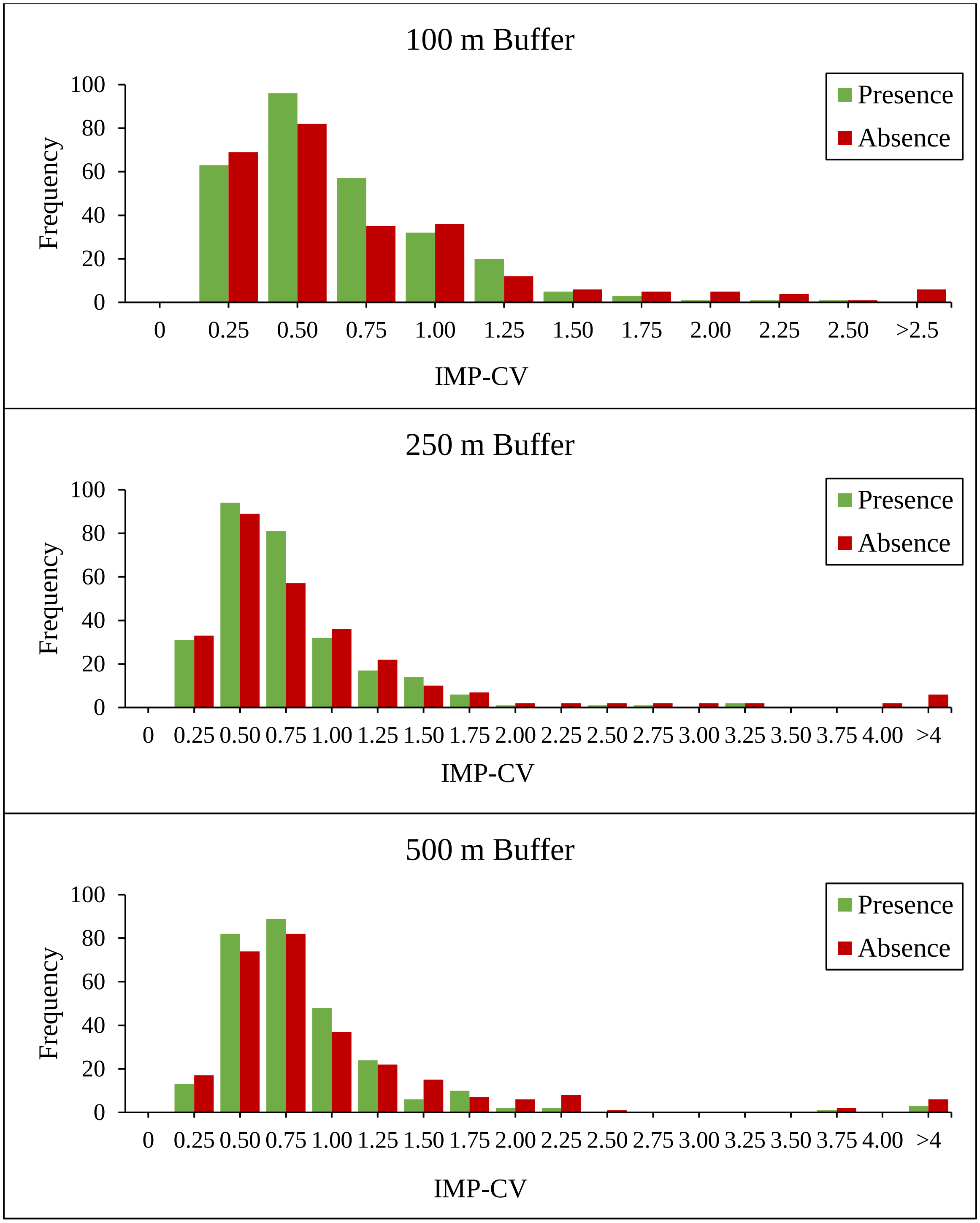

Figure 7. Frequency of the coefficient of variation of percent impervious surface (IMP-CV) values for the Monk Parakeet (*Myiopsitta monachus*) presence and pseudo-absence locations across all three buffered distances. Because CV is not defined when the mean is 0, some of the observations had to be removed, resulting in a smaller sample size compared to IMP-mean (100 m, n = 540; 250 m, n = 554; 500 m, n = 557).

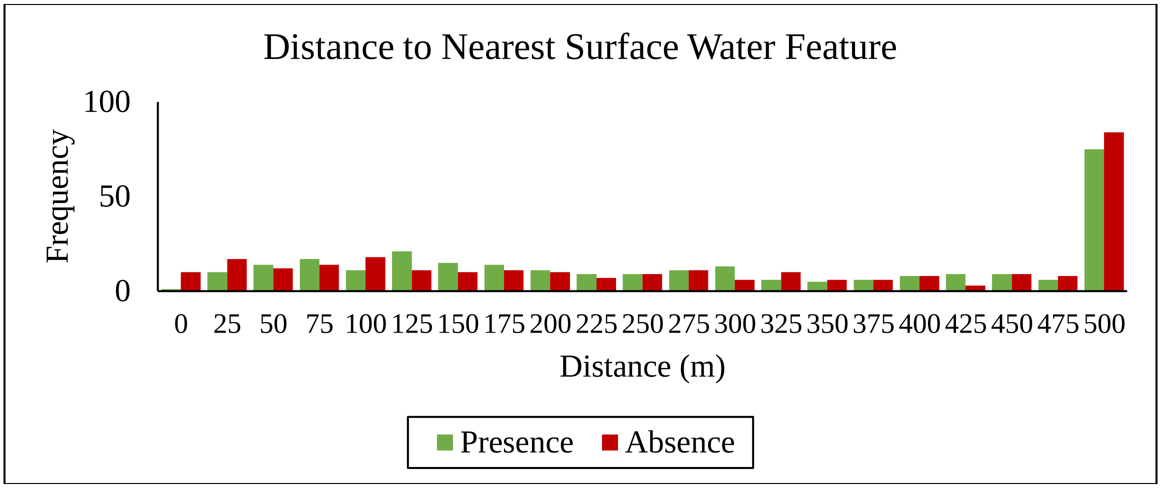

Figure 8. Frequency of the distance to nearest surface water feature values for the Monk Parakeet (*Myiopsitta monachus*) presence and pseudo-absence locations. As the distance to the nearest water source does not change between different buffer sizes, only one figure was constructed. Of the presence locations, 72 had a value of 500 m, and for the pseudo-absence locations, 77 had a value of 500 m.

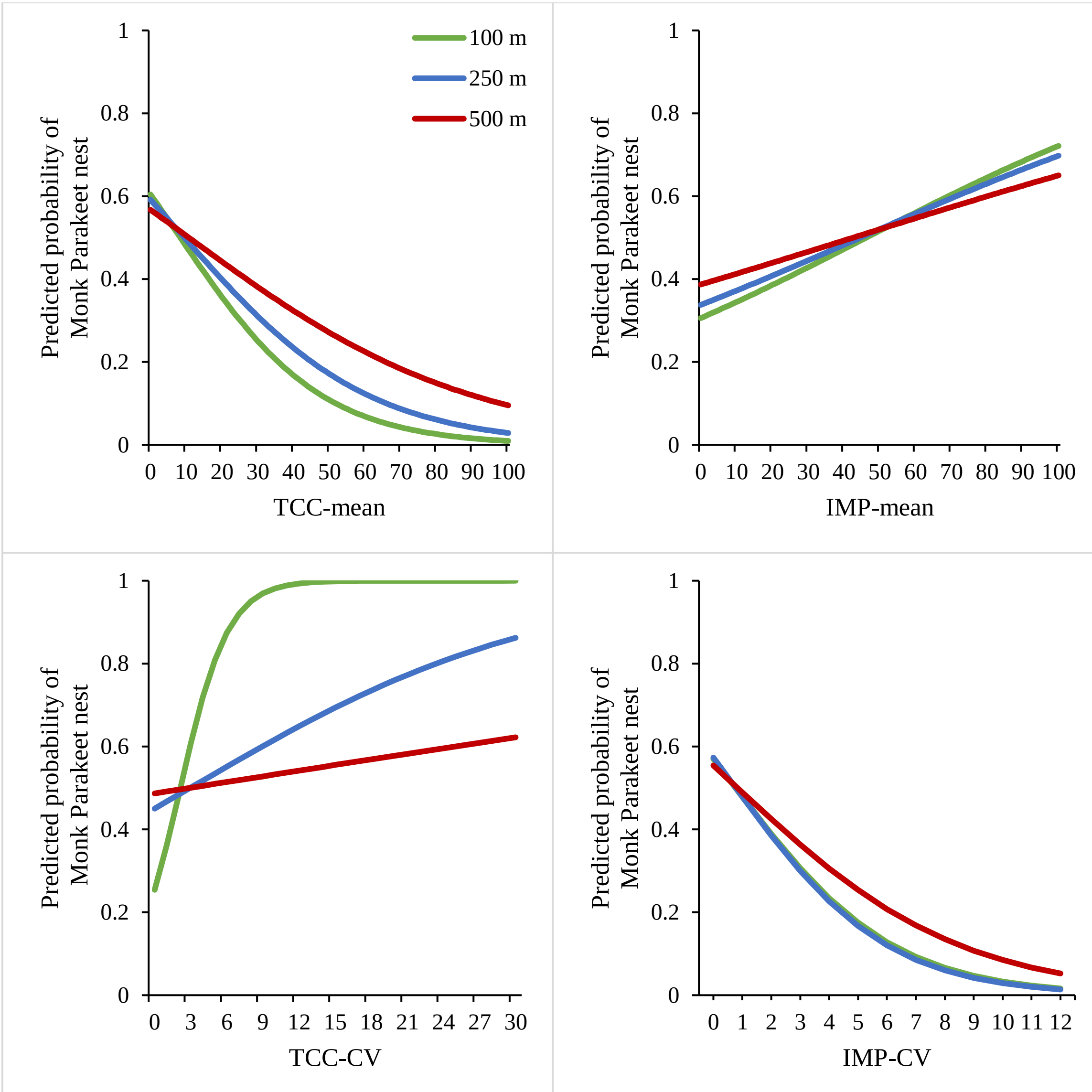

Figure 9. The predicted probability of the presence of Monk Parakeet (*Myiopsitta monachus*) nests based on the value of four of the primary environmental variables, shown across all three buffer sizes. The graphs are displayed as: top left - mean tree canopy cover (TCC-mean), top right - mean percent impervious surface (IMP-mean), bottom left - coefficient of variation of tree canopy cover (TCC-CV), and bottom right - coefficient of variation of percent impervious surface (TCC-CV). Maximum x-axis values represent the respective approximate maximum values of the environmental variables (see Table 1 for further details).

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