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Effects of Forest Patch Size and Shape on Breeding Bird Species Richness

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A Red-eyed Vireo feeding its young in Arms Forest.

Abstract

Forests are of great value to many bird species, especially neotropical migrants. However, in urbanized ecosystems, much of this habitat is fragmented. Previous studies have shown that forest fragmentation can affect breeding bird richness and abundance, but these studies are limited in scope. In this study, I assessed the effect of forest fragmentation on breeding bird communities in Burlington, Vermont, USA. I surveyed 14 fragmented forest patches between 4.2 and 40.1 hectares in size to determine how the richness of breeding bird species varies with patch size and perimeter-area ratio. I found a trend of increasing breeding

bird species richness as forest patch size increases, but no evidence of an effect of perimeter-area ratio on species richness. These data will be valuable for land management, restoration, and conservation initiatives in the area.

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Introduction

Urban and suburban development has impacted a variety of bird species. Habitats are created and destroyed, while some are isolated from others by roads and altered habitats, affecting connectivity (Ortega and Capen, 2002). Generally, many avian populations decline as a result of urbanization, notably those of forest-dwelling species (Archer et al., 2019). This is because habitat is converted to other land uses and the remaining forest patches are smaller and isolated, leading to areas becoming unsuitable for feeding and nesting. Green spaces in urban areas can provide habitat for forest-dwelling birds, as has been shown in previous studies (Lepczyk et al., 2017). Buffers, native forest fragments, and naturalistic urban parks have all been shown to provide suitable habitat for these species (Pennington and Blair, 2011).

After the publication of MacArthur and Wilson's (1967) book on island biogeography, researchers began to link issues of patch size and isolation to terrestrial ecosystems. This research has shown that many species are area-sensitive, requiring forest patches of a minimum size to sustain them and their broods (Bayard and Elphick, 2010). Each species has a different level of area sensitivity, but this phenomenon is most pronounced in forest-interior species. Forest loss will have a negative impact on the carrying capacity of all birds reliant on these habitats, but when forest loss is coupled with isolation, it will have a disproportionate impact on area-sensitive species (Bayard and Elphick, 2010). Area-sensitive species are negatively affected by the presence of forest edges, which are generally drier, have greater vegetation density, support more non-native species and predators (Baldi and Batary, 2004). In addition to these factors, the Brown-headed Cowbird (*Molothrus ater*), an avian brood parasite that reduces nest success in a variety of forest bird species, is more common around forest edges (Baldi and Batary, 2004, Robinson et al., 1995). The impacts of forest edges are known as "edge effects," and as a result of these impacts, many forest-dwelling species need a "core" habitat in which to reside. These species are known as forest interior specialists (Robbins et al., 1990). For example, a Scarlet Tanager (*Piranga olivacea*) pair may require a continuous patch of forest several times larger than its territory size to successfully breed due to some of the forest being edge habitat (Roberts and Norment, 1999). If the remaining forest patches are sufficiently small, habitat may become unsuitable for some species, leading to local extirpation (Van der Hoek et al., 2015). Despite habitat restoration being proven to help birds, some species may not nest in an area no matter how much restoration work is done.

Area-sensitivity is not a standard and varies by species. For example, in a hypothetical 100-hectare forest fragment, nesting Red-eyed Vireos (*Vireo olivaceus*) would be almost guaranteed to be present, yet there would only be around a 50% chance of finding nesting Scarlet Tanagers (Robbins et al., 1990). This is because each species has different feeding methods, nesting behaviors, and other ecological requirements that make them more or less sensitive to edge effects. In some cases, edge effects can work inversely as well, with species such as the House Wren (*Troglodytes aedon*) being most common around forest edges, while being nearly absent in large forest tracts (Robbins et al., 1990, Valente and Betts, 2018).

In an urban/suburban environment, area-sensitivity is a major factor when compared to more rural areas because of the increased severity of edge effects (Pennington and Blair, 2011). Yet many species still use urban parks, woodlots, and other refuges because avian species survival is not entirely bound by availability of large enough unbroken tracts of habitat. Some species, such as the Scarlet Tanager have been known to wander between forest patches if they are unpaired (Fraser and Stuchbury, 2004). Others, such as the Swainson's Thrush (*Catharus ustulatus*), are known to utilize various-sized patches during migration, including those far too small to support breeding pairs (Matthews and Rodewald, 2010). Still, even outside of the breeding season, many species continue to prefer larger patches of habitat during migration (Keller and Yahner, 2007, Matthews and Rodewald, 2010).

As a result of species-specific variation across area-sensitivity and other habitat needs of different species, breeding bird richness is not necessarily greatest in forest interiors. In fact, studies have shown that richness is in fact greatest around forest edges due to being suitable to both edge-dependent species and species that do not require forest interiors (Valente and Betts, 2019). Prior studies have shown that different groups of species show variation in the probability of occupancy when habitats are disturbed or altered (Faccio, 2004, Germaine et al., 1997). Therefore, forest patch size may not necessarily correlate with avian species richness, depending on what group(s) of species is being studied (Valente and Betts, 2019). The main correlation would be within specific groups of species, especially area-sensitive forest interior species (Robbins et. al., 1990).

Burlington, Vermont, USA is a city containing numerous habitats, such as forests, wetlands, and agricultural lands, which are all utilized by migratory and breeding bird species. Forest patches, one of the most important habitat types, come in various sizes in Burlington, with some in excess of twenty hectares, while others are much smaller (Beckett, 2017). Forests are of unique importance in that they support a large variety of songbird species (Passeriformes), many of which are only present for part of the year (the breeding season). These ecosystems are one of the more common types of “natural” habitats in Burlington. What separates these urban/suburban patches from the larger tracts of forests found outside of Burlington is that most are surrounded by human development, leading to many areas being isolated or fragmented from other patches of forest (Beckett, 2017).

One commonly used survey method for documenting variation in breeding bird communities is a breeding bird atlas. Breeding bird atlases note the presence of species in specific areas to document where species nest and if avian presence in these areas changes over time (Van der Hoek et al., 2015). This is done through regular visits to sites, documenting species composition and breeding behaviors of each species. These atlases can be used to paint an accurate picture of species occupancy and distribution and how they change over time (Renfrew, 2013, Hudson et al., 2017). Breeding bird surveys are a different method that provide abundance data but are more difficult and time-consuming because exact counts of individuals must be made for each species, whereas this metric is unnecessary for most occupancy studies. Breeding bird atlases can quantify population shifts locally and regionally over time, as well as determine which areas are most critical for each species (Renfrew, 2013, Rosenberg et al., 2017, Sauer et al., 2017). Since many species of neotropical-nearctic migrants are area-sensitive, populations have declined in areas with significant habitat loss and fragmentation (Van der Hoek et al., 2015, Sauer et al., 2017,). If there are species of concern utilizing and/or breeding in an area, protection and/or restoration can be targeted to better conserve biodiversity (Downes et al., 2016). A study predicting occupancy based on forest patch size and shape could allow conservationists to focus less on surveying bird populations and more on working with partners to protect the land.

The relatively high human population density within Burlington has led to extant forest patches being somewhat small in area. Consequently, avian richness in these patches may be different than that of more contiguous forests. Although forest fragments in many developed areas do support a diverse assemblage of breeding bird species (Fraser and Stuchbury, 2004, Keller and Yahner, 2007), no systematic inventory had been conducted that addresses the relationship between forest patch size and species composition in the city of Burlington, Vermont. In this study, I tested the hypothesis that larger forest patches contain greater breeding bird species richness and in particular, a greater number of area-sensitive species. This trend has been observed before in other areas, such as the Mid-Atlantic region of the United States (Robbins et al., 1990), but research into this phenomenon within urban/suburban environments appears scarce. Through this study, I aimed to document the distribution of forest-nesting species across forest patches in Burlington to quantify the relationship between patch size/shape and breeding bird richness.

This information would be best used by local agencies such as the Burlington Parks, Recreation, and Waterfront and state agencies such as the Vermont Fish and Wildlife Department. Additionally, it could inform private landowners, such as the University of Vermont, of how valuable their property is for breeding birds ecologically (Beckett, 2017). In addition, these surveys can help bird watchers, which make up 45.1 million Americans as of 2016 (United States Census Bureau, 2016), find sites that may provide the avian species they desire, especially for those who want to learn more about nature and ecology (Downes et al., 2016, Zhou et al., 2019).

Methods

I conducted surveys of bird species assemblages in 14 readily accessible forest patches of varying sizes within the Burlington city limits. I used satellite imagery to limit forest patches to sites with no unnatural breaks or clearings (apart from the actual edges). I also attempted to include forest patches that were most similar in forest type, species composition, and age to minimize the influence of factors other than size and perimeter-area ratio. I conducted site visits in the weeks leading up to the data collection period to narrow the number of sites down to a subset that I could consistently survey. The varying sizes ensured a range of patch sizes to assess the effects of fragmentation on breeding bird species richness. Sites ranged from 4.16 to 40.01 hectares in size. ArcGIS Pro was used to determine a precise area and perimeter of each site. This was done by manually drawing polygons based on canopy cover from 2016 land cover imagery with a resolution of 0.25 m^2 (Vermont Center for Geographic Information, 2017).

Table 1: The 14 forest patches in Burlington, Vermont that were surveyed for breeding bird species richness in 2021. Respective patch area and perimeter-area ratios are shown as well. Sites are ordered by largest to smallest area, while perimeter-area ratios use perimeter in meters divided by square meters. Note that perimeter-area ratio is not necessarily correlated with patch size.

Site	Area (ha)	Perimeter-Area Ratio
Centennial Woods (Large)	40.06	43.91
Arms Forest	33.55	67.63
Rock Point	27.91	42.25
Trinity Woods	15.46	31.85
Appletree Point Park	14.27	55.44
Intervale Calvert Trail	12.43	41.89
McKenzie Park	11.99	52.62
Starr Farm Park	10.97	33.87
Leddy Park (Large)	9.51	35.15
Centennial Woods (Small)	9.15	49.91
Ethan Allen Park	8.42	55.55
Salmon Hole (West)	7.05	23.73
Leddy Park (Small)	5.09	31.28
Salmon Hole (East)	4.16	18.69

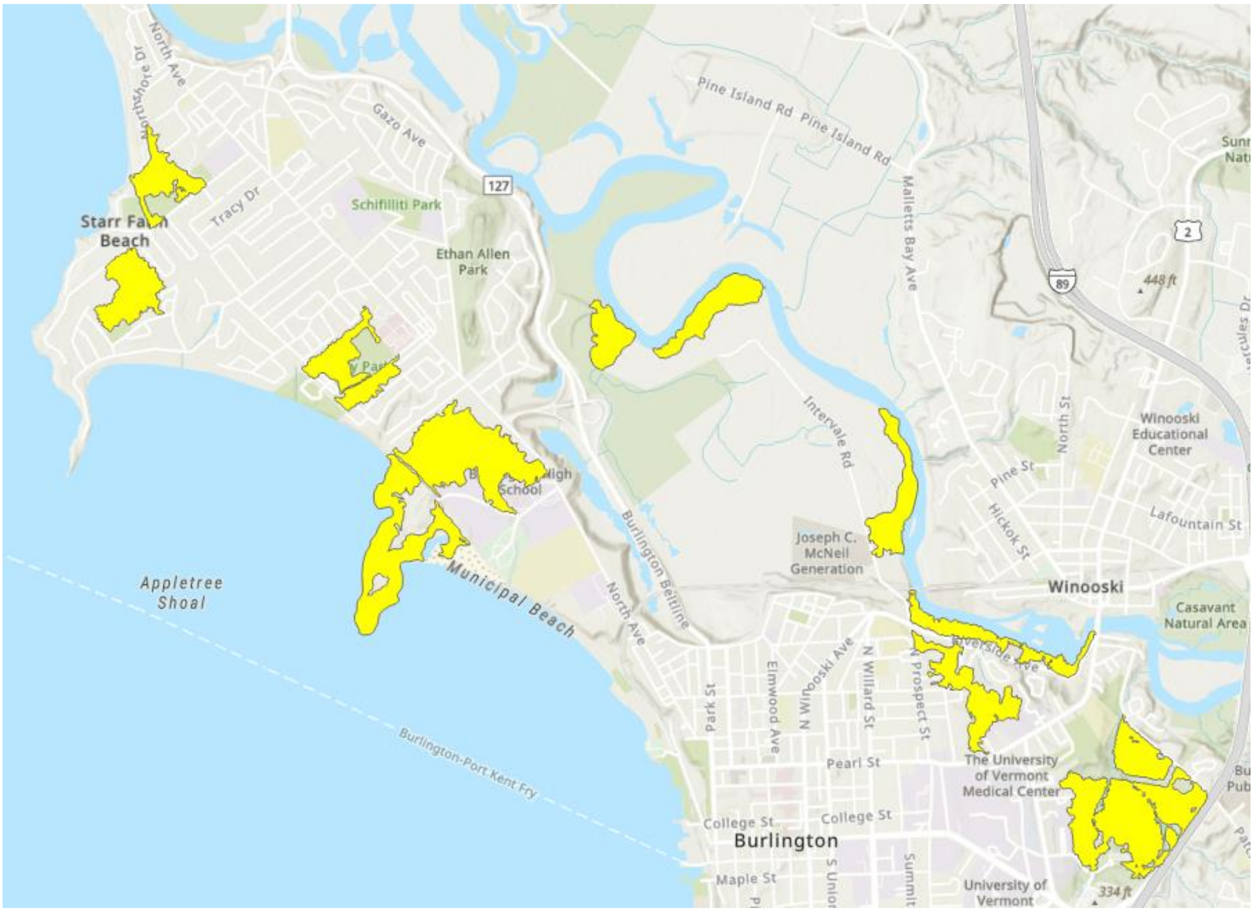

Figure 1: A map of the 14 forest patches (highlighted in yellow) where breeding bird surveys were conducted in the city of Burlington.

Data collection took place 5-6 days a week. This cycle repeated until seven visits were made to each site between May 19 and July 28, 2021. This period was chosen because most migratory breeding bird species in Burlington arrive on territories by the last two weeks of May, while breeding concludes for most of these species by the end of July (Keller et al., 2007). As birds are at different stages of breeding throughout the season, detection was expected to vary based on the date. By conducting surveys throughout the breeding season, I expected to document breeding for species that have disparate nesting cycles. The number of sites surveyed per day varied based traversability within patches, and travel time between them. The smallest sites could be traversed within as little as a half hour, while the larger sites could take three hours or more to cover. These visits were conducted mostly in the early to mid-morning hours, as birds are typically most active and vocal during this time (Trinka et al., 2006). Data on observation start and end times were recorded for each site, and site visits did not occur in heavy rain or wind due to the movement of arboreal bird species being less discernible.

Although all species detected in each forest patch were recorded, I focused on documenting breeding activity to get a thorough assessment of the breeding bird richness at each patch. Standard breeding bird atlassing protocols divide breeding behaviors into different categories. Most important is “confirmed breeding,” with behaviors within this category including occupied nests, young, nest building, and adults carrying food or fecal sacs. A less precise category, “likely breeding,” includes individuals consistently singing in the same area, copulation/courtship, territorial defense behavior showing behavioral signs of having formed a mated pair (Renfrew, 2013, Anich, 2015). Wrens and woodpeckers building nests are exceptions to the likely breeding definition, as these groups are known to build multiple nests before settling on a final nest site (Kaufman, 2019, Jackson and Ouellet, 2020), though no observations of this type appeared in the study. The citizen science mobile application eBird was used to record all sightings. Even though abundance, which eBird records, is not the primary factor of the study, every species detected by sight or sound within each patch was recorded to provide the best possible assessment of avian richness. Species that were observed utilizing study areas for hunting, roosting, or other common behaviors not associated with breeding are still noted in the category “present.” These species could be breeding in nearby areas, be unpaired birds looking for territories (Fraser and Stuchbury, 2004), or actually be breeding in a survey area, yet displayed no signs of breeding when observed.

In the first few weeks of these surveys, migratory birds were still traveling through the Burlington area and singing. Many species nest both in Burlington and well north of the city, so there may be some error based on consistently singing migrants not lingering. Species observed whose breeding ranges falling definitively outside of the Burlington area (Rimmer and McFarland., 2020, Moldenhauer and Regelski, 2020), such as Tennessee Warbler (*Leiothlypis peregrina*) and Northern Parula (*Setophaga americana*) were not included in the data, as they are not expected to attempt to nest in Burlington. Species seen flying overhead or observed outside of the patches were also not included, as they were not interacting with the habitat. One limitation of these surveys is that some species exhibit breeding behaviors before (e.g., Northern Cardinal; *Cardinalis cardinalis*) or after (e.g., American Goldfinch; *Spinus tristis*) the data collection period (Nagy and Holmes, 2005). However, these are only a small portion of the species that were expected to use these sites, so the surveys should still give a good assessment of species richness.

After the surveys were completed, the data were organized in Microsoft Excel by species, location, and, most importantly, the species observed exhibiting breeding behaviors. The data were then combined with previously taken GIS measurements of patch sizes and perimeter-area ratios, where I used linear regression to determine the relationship between species richness and patch sizes and perimeter-area ratios. Because of the different levels of certainty associated documenting breeding status (confirmed vs. likely vs. present), I used three different metrics for species richness, each successive upon the one(s) prior. Confirmed breeding species richness is assessed as is, while likely breeding species richness is combined with confirmed for the second metric, and both of these values are combined with present species for the third metric.

Results

In total, 49 species were confirmed breeding across all sites, with a total of 59 species that were confirmed and likely breeders and 72 species present in total. The most common species present were Red-eyed Vireo (*Vireo olivaceus*), Downy Woodpecker (*Dryobates pubescens*), Northern Cardinal, and Tufted Titmouse (*Baeolophus bicolor*), which were the only species observed at every patch, while the most common confirmed breeding species and confirmed + likely breeding species was Tufted Titmouse. There were 22 species that were only confirmed at a single site, as well as 15 confirmed + likely species and 15 present species only found at a single site. Confirmed breeders found at only a single site include the Ruby-throated Hummingbird *(Archilochus colubris*), Winter Wren (*Troglodytes hiemalis*), and Least Flycatcher (*Empidonax minimus*). This is likely due to the substantial effort needed to document nesting for these less common species. Eleven of the 22 species that were confirmed breeding at a single site were found in the three largest forest patches, suggesting that these sites play disproportionately important role in local avian biodiversity. Some common backyard species were uncommon or absent as breeders in forest patches, likely because areas around bird feeders and backyards provide better habitat. These included Carolina Wren (*Thryothorus ludovicianus*), Mourning Dove (*Zenaida macroura*), and Chipping Sparrow (*Spizella passerina*).

Among the patches, Centennial Woods (large), Arms Forest, and Rock Point were the top three areas for species richness in all three assessments (though not always in that order). These were the three largest patches in the study. Centennial Woods (large) held the greatest number of present species at 47 and the greatest number of confirmed + likely breeders at 33. Arms Forest had the greatest number of confirmed breeders at 19. Both Leddy Park patches, Appletree Point Park, Salmon Hole (east) and Starr Farm Park had the lowest species richness, with Leddy Park (small) having the fewest confirmed breeders at 2 and the least confirmed + likely breeders at 8. Salmon Hole (east) had the fewest number of present species observed at 18. Some species, such as Wood Thrush (*Hylocichla mustelina*) and Ovenbird (*Seiurus aurocapilla*), were mostly confirmed or likely breeders in larger patches, suggesting that they require more core habitat than other species. By contrast, the most common breeders mentioned previously are mostly habitat generalists, which makes sense.

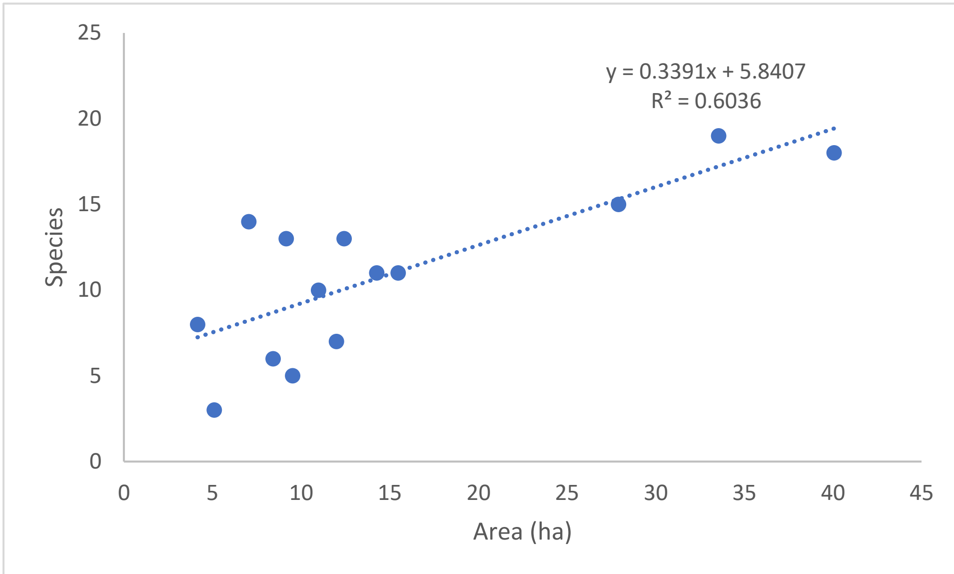

Figure 2: Relationship between the number of confirmed breeding bird species and forest patch size (ha) in Burlington, Vermont at 14 sites surveyed during the 2021 breeding season.

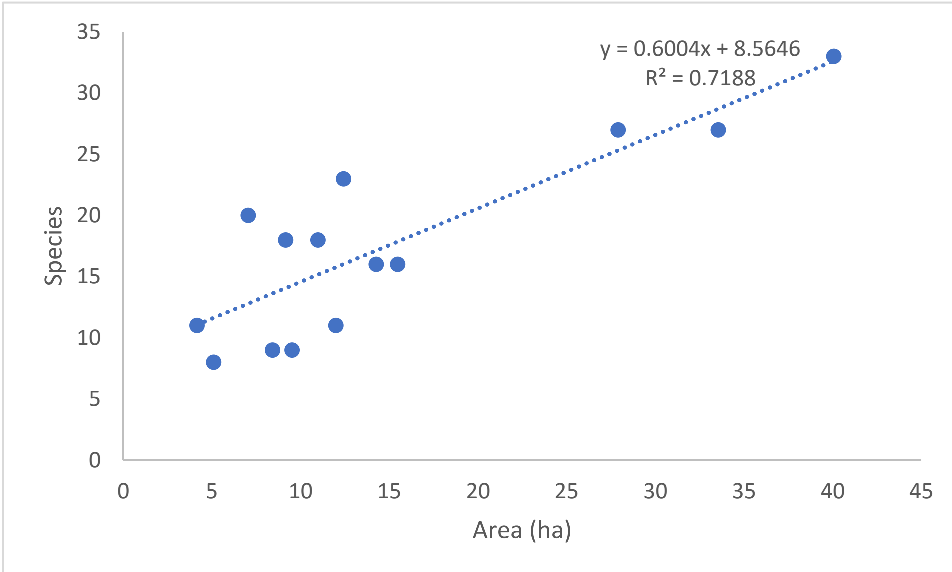

Figure 3: Relationship between the number of confirmed and likely breeding bird species and forest patch size (ha) in Burlington, Vermont at 14 sites surveyed during the 2021 breeding season.

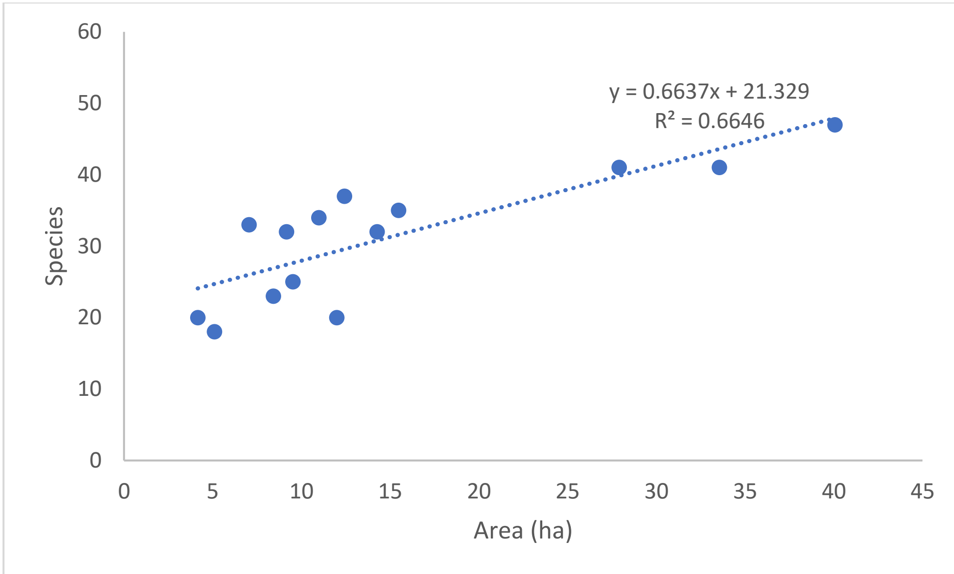

Figure 4: Relationship between the number of species present and forest patch size (ha) in Burlington, Vermont at 14 sites surveyed during the 2021 breeding season.

Table 2: Confirmed breeding bird species at each site. Sites are ordered from largest (left) to smallest (right). Species are ordered from those confirmed at the greatest number of sites (top) to those confirmed at the fewest (bottom; see column on right). Site names: CWL=Centennial Woods (Large), AF=Arms Forest, RP=Rock Point, TW=Trinity Woods, MP=McKenzie Park, ICP=Intervale Calvert Trail, APP=Appletree Point Park, CWS=Centennial Woods (Small), SFP=Starr Farm Park, EAP=Ethan Allen Park, LPL= Leddy Park (Large), SHW=Salmon Hole (West), LPS=Leddy Park (Small), SHE= Salmon Hole (East). Species names are notated using four-letter banding codes as established by the North American Bird Banding Program. Full common and scientific names of species with associated band codes can be found in Appendix A.

Species	CWL	AF	RP	TW	MP	ICP	APP	CWS	SFP	EAP	LPL	SHW	LPS	SHE	Total Sites
TUTI	1	1	0	1	1	1	1	1	1	1	1	1	0	1	12
BCCH	1	1	1	1	1	1	1	1	1	1	0	1	0	0	11
AMRO	1	1	1	1	1	1	1	1	0	1	0	1	0	1	11
NOCA	0	1	1	1	1	1	1	0	0	1	1	1	1	0	10
SOSP	1	1	1	0	1	1	0	0	0	1	1	1	0	1	9
GRCA	0	1	1	0	1	0	0	1	0	1	0	1	0	1	7
HOWR	0	1	1	0	1	1	1	0	0	1	0	0	0	0	6
AMRE	0	1	1	0	1	1	0	0	0	1	0	1	0	0	6
DOWO	1	1	0	1	0	1	0	0	0	0	0	0	0	1	5
REVI	1	1	1	0	0	0	0	0	0	0	1	1	0	0	5
COGR	1	0	0	0	0	0	1	0	0	1	0	1	0	1	5
WOTH	1	1	1	0	0	0	0	1	0	0	0	0	0	0	4
BHCO	0	1	0	0	1	0	0	0	1	0	0	1	0	0	4
CHSP	0	0	0	1	0	0	0	0	1	0	1	0	1	0	4
YEWA	0	0	0	0	1	1	0	0	0	1	0	0	0	1	4
PIWA	1	1	1	1	0	0	0	0	0	0	0	0	0	0	4
NOFL	0	0	0	1	0	1	1	0	0	0	0	0	0	0	3
GCFL	0	1	0	1	0	0	0	1	0	0	0	0	0	0	3
BLJA	0	0	1	0	0	0	0	0	0	1	0	0	0	1	3
WBNU	1	0	1	0	0	1	0	0	0	0	0	0	0	0	3
BAEO	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2
EAPH	0	0	1	0	0	0	0	0	0	0	0	1	0	0	2
RBNU	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2
VEER	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2
BAOR	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
CSWA	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2
YBCU	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
RTHU	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
BEKI	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
RBWO	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
HAWO	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
EAWP	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
LEFL	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
WAVI	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
AMCR	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
CORA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
NRWS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
BRCR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
CAWR	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
WIWR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
EUST	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
CEWA	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
HOFI	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
RWBL	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
COYE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SCTA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
INBU	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
RBGR	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Total Species	18	19	15	12	11	13	7	10	5	13	6	14	2	8	

Table 3: Six regression analyses comparing patch size and perimeter-area ratio with three different measures of breeding bird species richness in Burlington, Vermont in 2021. Outputs shown are *F* statistic, adjusted R^2, and *p* values. R^2 values differ from the prior three figures due to being adjusted. Degrees of freedom for all six analyses was 12.

Dependent Variable	Breeding Category	Adjusted R^2	*F* Statistic	*p* Value
Patch Size	Confirmed	0.57	18.27	<0.01
Patch Size	Likely	0.70	30.67	<0.01
Patch Size	Present	0.64	23.77	<0.01
Perimeter-Area Ratio	Confirmed	0.03	1.42	0.26
Perimeter-Area Ratio	Likely	-0.01	0.84	0.38
Perimeter-Area Ratio	Present	-0.01	0.92	0.36

The results showed a significant linear correlation between species richness and forest patch size in all three breeding categories (all p values < 0.01). However, some of the correlation is not explained by area alone, as the R^2 value ranged between 0.57 and 0.70. The correlation was greatest in confirmed + likely breeding bird species with an R^2 value of 0.70, Perimeter-area ratio did not appear to have any relationship with species richness, as all three analyses had R^2 values near zero and none of their p values were significant. Therefore, the data show that area is a much more important metric in influencing breeding bird species richness than perimeter-area ratio.

Discussion:

The results from this study support my hypothesis that breeding bird species richness increases with increasing forest patch size. This holds true for each of the three different metrics for assessing species richness. As for the other factor analyzed, I found no relationship between perimeter-area ratio and species richness. Looking at species data, there is also evidence that some species are generalists, some are area-sensitive, and some are too uncommon to define a trend.

The different statistical values associated with each analysis show that confirmed + likely breeders vs. patch size has the strongest correlation of all six, with an R^2 value of 0.70. This could mean that in future surveys of this variety, effort should be primarily focused on finding signs suggesting breeding rather than confirmation or present species in order to produce the best results. By decreasing time spent looking for signs of nesting confirmation (nests, carrying food, etc.), researchers should be able to visit more sites across a larger area.

While the correlation between patch size and species richness is strong, but there is still unexplained variation. Several factors may be contributing to this. One factor is that all but the three largest patches were within a narrow size range, between 4 and 16 hectares, while the largest patch was over 40 hectares. A wide range of species richness values were calculated for the smaller patches, especially for the confirmed metric. A more equal distribution of patch sizes might provide a more accurate assessment of the relationship between patch size and species richness.

A second reason as to why the correlation doesn't explain some of the data is likely the types of forest habitat present at each site. While every site consisted of forest habitat, each one had varying features. These included the ratio of coniferous to deciduous vegetation, distance from water, understory density, and proximity to roads, all of which could affect species composition. For example, House Wrens were recorded breeding at nearly every site where there were open deciduous woodlands but were unconfirmed or not present at sites with a dense shrub layer or mostly coniferous forest.

By contrast, I found no correlation between species richness and perimeter-area ratio for any of the three categories of breeding confirmation. This might be due to area increasing much more rapidly than perimeter as one increases the size of a polygon. Many of these patches also had irregular shapes, causing the perimeter-area ratio to have little correlation with patch size. Additionally, there is less variation in perimeter-area ratios than with patch size, which is likely a contributing factor to the lack of a relationship with species richness. With the fairly strong correlation between species richness and area, it is clear that area is a much stronger indicator than perimeter-area ratio for species richness. In fact, because the R^2 values are near-zero for perimeter-area ratios, this variable has no effect on species richness.

A few environmental variables could have impacted the study. One could be the weather patterns, as they vary from year-to-year. The differences in the study period were considerable, as it was much drier than usual in May and June, followed by a wetter-than-average July (Weather Underground, 2022). As it is not a primary focus of the study, the effects of such weather patterns were not looked at in depth, but they may have had a role in settlement patterns of breeding birds at the end of spring migration in May.

Another variable was the mass emergence of caterpillars, particularly those of Spongy Moths (*Lymantria dispar*) in June. These moths are an invasive species whose caterpillars alter habitat by defoliating many deciduous tree species, which can decrease the amount of canopy cover (a factor that could affect habitat suitability). Additionally, although Spongy Moth caterpillars are hard for birds to ingest due to their spines, a few species do actively consume them, most notably cuckoos (*Coccyzus* spp.), so their distributions may be altered as well (Barber et al., 2008). Other bird species were observed feeding on the more ingestible adult moths in the first few weeks of July, such as Eastern Wood-Pewees (*Contupus virens*) and Black-capped Chickadees (*Poecile atricapillus*). This suggests that they may benefit from the large number of moths present at this time, especially if this is when young birds are still dependent on their parents.

Lastly, isolation is a factor that was not accounted for in the study. Some patches (such as Arms Forest and Rock Point) are close together, while others, such as Starr Farm Park, are far from other green spaces. Based on this, it is reasonable to conclude that this study is subject different levels of island biogeography for many patches. As such, one could argue that some areas be combined if closer than a certain distance, while some isolated patches may be best excluded. A separate analysis aiming to find a correlation between patch isolation and species richness may be a valuable follow-up in order to quantify how much of an effect (if any) island biogeography has on breeding bird species.

These data can be valuable for city planning, in particular for stakeholders interested bird conservation in Burlington. Both governmental organizations and private environmental and land stewardship organizations could focus habitat preservation efforts on patch sizes that are more critical to breeding bird communities in Burlington. There may also be opportunities for habitat restoration that could either lead to changes in the size of forest patches or increased connectivity between isolated patches. Environmental analysts could also use the data to assess the effect of new development on local breeding bird communities. Finally, this would benefit the general public, particularly wildlife watchers who want to observe breeding birds close to home. A few examples of potential stakeholders include Burlington Geographic and the Half-Earth Project. The findings of this project will be sent to these stakeholders, and I would be open to making them publicly accessible.

As this is just one study concerning area sensitivity in a developed area, subsequent studies could be conducted to see if trends hold up, especially across certain species. For them to be most relevant, they would need to take place in areas where bird diversity and vegetation types are similar to Burlington, Vermont. These data could be used to make more generalized predictions in cities and towns across New England instead of just in Burlington. Additionally, studies focused on specific species of concern (e.g., Wood Thrush,) could use similar methods while using less resources than a study of all species.

Conclusion

Across the nation, a majority of bird species are in decline due to various causes, including habitat loss. Fragmented habitat caused by land use change affects different species in different ways. This study found that breeding bird species richness in Burlington, Vermont, USA increases with increasing forest patch size, which is in line with previous studies from elsewhere. Notably, it also shows trends concerning how large areas need to be for some species to breed in them. Having a better understanding of which species are found nesting in and utilizing different-sized forest patches could provide organizations and governments information as to what forest patch sizes would be most worth preserving and/or restoring. This knowledge would help to better protect and conserve local breeding bird species and their habitats.

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Appendix A

The table below contains the common name, scientific name, and four-letter banding code for all 72 species documented in the "present" category and above.

Species	Scientific Name	Band Code
Wood Duck	*Aix sponsa*	WODU
Mourning Dove	*Zenaida macroura*	MODO
Yellow-billed Cuckoo	*Coccyzus americanus*	YBCU
Black-billed Cuckoo	*Coccyzus erythropthalmus*	BBCU
Ruby-throated Hummingbird	*Archilochus colubris*	RTHU
Green Heron	*Butorides virescens*	GRHE
Turkey Vulture	*Cathartes aura*	TUVU
Osprey	*Pandion haliaetus*	OSPR
Cooper's Hawk	*Accipiter cooperii*	COHA
Red-tailed Hawk	*Buteo jamaicensis*	RTHA
Barred Owl	*Strix varia*	BADO
Belted Kingfisher	*Megaceryle alcyon*	BEKI
Red-bellied Woodpecker	*Melanerpes carolinus*	RBWO
Downy Woodpecker	*Dryobates pubescens*	DOWO
Hairy Woodpecker	*Dryobates villosus*	HAWO
Northern Flicker	*Colaptes auratus*	NOFL
Pileated Woodpecker	*Dryocopus pileatus*	PIWO
Merlin	*Falco columbarius*	MERL
Peregrine Falcon	*Falco peregrinus*	PEFA
Great Crested Flycatcher	*Myiarchus crinitus*	GCFL
Eastern Kingbird	*Tyrannus tyrannus*	EAKI
Eastern Wood-Pewee	*Contopus virens*	EAWP
Least Flycatcher	*Empidonax minimus*	LEFL
Eastern Phoebe	*Sayornis phoebe*	EAPH
Warbling Vireo	*Vireo gilvus*	WAVI
Red-eyed Vireo	*Vireo olivaceus*	REVI
Blue Jay	*Cyanocitta cristata*	BLJA
American Crow	*Corvus brachyrhynchos*	AMCR
Fish Crow	*Corvus ossifragus*	FICR
Common Raven	*Corvus corax*	CORE
Black-capped Chickadee	*Poecile atricapilla*	BCCH
Tufted Titmouse	*Baeolophus bicolor*	TUTI
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	NRWS
Cedar Waxwing	*Bombycilla cedrorum*	CEWA
Red-breasted Nuthatch	*Sitta canadensis*	RBNU

White-breasted Nuthatch	*Sitta carolinensis*	WBNU
Brown Creeper	*Certhia americana*	BRCR
Blue-gray Gnatcatcher	*Polioptila caerulea*	BGGN
House Wren	*Troglodytes aedon*	HOWR
Winter Wren	*Troglodytes hiemalis*	WIWR
Carolina Wren	*Thryothorus ludovicianus*	CAWR
Gray Catbird	*Dumetella carolinensis*	GRCA
Brown Thrasher	*Toxostoma rufum*	BRTH
European Starling	*Sturnus vulgaris*	EUST
Veery	*Catharus fuscescens*	VEER
Wood Thrush	*Hylocichla mustelina*	WOTH
American Robin	*Turdus migratorius*	AMRO
House Sparrow	*Passer domesticus*	HOSP
House Finch	*Haemorhous mexicanus*	HOFI
American Goldfinch	*Spinus tristis*	AMGO
Chipping Sparrow	*Spizella passerina*	CHSP
Song Sparrow	*Melospiza melodia*	SOSP
Baltimore Oriole	*Icterus galbula*	BAOR
Red-winged Blackbird	*Agelaius phoeniceus*	RWBL
Brown-headed Cowbird	*Molothrus ater*	BHCO
Common Grackle	*Quiscalus quiscula*	COGR
Ovenbird	*Seiurus aurocapilla*	OVEN
Northern Waterthrush	*Parkesia noveboracensis*	NOWA
Black-and-White Warbler	*Mniotilta varia*	BAWW
Nashville Warbler	*Leiothlypis ruficapilla*	NAWA
Common Yellowthroat	*Geothlypis trichas*	COYE
American Redstart	*Setophaga ruticilla*	AMRE
Blackburnian Warbler	*Setophaga fusca*	BLBW
Yellow Warbler	*Setophaga petechia*	YEWA
Chestnut-sided Warbler	*Setophaga pensylvanica*	CSWA
Black-throated Blue Warbler	*Setophaga caerulescens*	BTBW
Pine Warbler	*Setophaga pinus*	PIWA
Black-throated Green Warbler	*Setophaga virens*	BTGW
Scarlet Tanager	*Piranga olivacea*	SCTA
Northern Cardinal	*Cardinalis cardinalis*	NOCA
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	RBGR
Indigo Bunting	*Passerina cyanea*	INBU