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Review

Integrating Habitat Suitability in Urban Forest Ecosystem Service Assessments: Reflections from i-Tree Wildlife

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Abstract

Urban forests support wildlife populations across North America and the world. Yet, challenges remain for research and practice to integrate wildlife habitat as a core component of the myriad objectives that urban foresters manage. Ecosystem services have been adopted as a dominant paradigm in urban forestry for both advocacy and management, yet accounting for contributions to wildlife habitat does not fit squarely within typical ecosystem service frameworks. The i-Tree program, a suite of urban forest ecosystem service models and tools developed by the US Forest Service, presented an opportunity to link widely used urban forest assessment field protocols with indicators of suitable habitat. In this reflection piece, we demonstrate how the i-Tree Wildlife project assessed whether urban forest structural assessment methods could be applied to assess wildlife habitat provision, operationalizing the fundamental question "How do urban forests support wildlife?" We describe the development process for integrating bird habitat suitability models for 12 species present in the northeastern US, ten native and two non-native birds, into the flagship i-Tree Eco tool. We offer reflections, challenges, and opportunities from this process. Ultimately, the improvement of ecosystem assessment tools like i-Tree can assist practitioners who aim to manage healthy and productive urban forests that benefit people and wildlife.

Keywords: bird habitat; decision support tool; ecosystem services; i-Tree; urban wildlife

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1. Introduction

Urban forests are complex social and ecological systems that provide a multitude of irreplaceable benefits to both city dwellers and populations beyond city limits [1–4]. These benefits range from processes that regulate our environment, like cleaning air and water, and providing shade, to more tangible items like food production and wood products, to the ways in which their functions support the foundations of the healthy ecosystems upon which biodiversity relies [5–7]. The science and practice of urban forestry have evolved over the last several decades in parallel with the modern concept of ecosystem services. The concept of ecosystem services was developed to quantify and communicate the many essential benefits that natural ecosystems contribute to human populations, which can easily be overlooked in economic analyses or management objectives [8–10]. Certain ecosystem services have been much easier to develop quantification methods for, such as wood products or carbon sequestration, while others have been more difficult, such as support of wildlife habitat and biodiversity [11–13]. Indeed, many have argued that some of the most foundational benefits of nature elude quantification entirely—such as cultural and spiritual connections [14]. Nonetheless, assessing the structure, function, and service of ecosystems provides an analytical framework to simplify the complexity of ecosystems and to work towards addressing questions like "How do urban forests support wildlife?" Importantly, this framework can also serve as a link between forestry and wildlife biology, traditionally separated by strong disciplinary boundaries.

In urban forestry, during the 1990s to early 2000s, US Forest Service scientists and partners began developing models and associated tools to quantify the ecosystem services that trees provide to urban areas [15,16]. In 2006, these efforts were brought together, in partnership with industry leaders in the US, and the i-Tree program was launched [17]. The i-Tree program advances science to model the ecosystem services of trees and operationalizes this science in a suite of urban forest ecosystem service assessment tools for diverse user groups. The core models encompass an array of ecosystem services, including air pollution removal and associated health effects, carbon storage and sequestration, avoided storm water runoff, and effects on building energy use [17]. Since its inception, i-Tree's urban forest assessment tools have been used in over 185 countries [17]. Because of i-Tree's global reach and user base, and its foundation on a robust urban forest structure data collection protocol, it is in many ways an ideal platform to assess diverse functions and services of urban forests, including as habitats for wildlife.

Understanding how urban forests support wildlife and biodiversity more broadly is a pressing question for managers, scientists, and communities [18–20], and yet, it is often left out of ecosystem service assessment models like i-Tree because of the complexity of factors required for consideration. Urban areas support biodiversity in many critical ways—from serving as stopover sites for migrating wildlife to encompassing sensitive habitat areas [20–24]. The benefits that urban residents receive from supporting biodiversity in their cities also vary and are highly context-specific, from the benefits of connecting with nature on an individual level to all of the benefits received from living within healthy ecosystems [25–29], given the various ecosystem services many wildlife species provide (e.g., seed dispersal, insect control, and consuming carrion [30]). In addition, the wildlife recreation industry has tremendous economic benefits. The most recent State of the Birds report estimates that 37% of the US adult population identifies as a birder, and birdwatching contributes approximately $279 billion to the US economy each year [31]. The majority of self-identified birders (70%) live in urban and suburban areas, and thus, a sizable proportion of the economic contribution likely reflects the urban wildlife recreation industry.

Because of these benefits to people, and an interest in contributing to biodiversity conservation, many practitioners and stakeholders seek to protect and promote wildlife and their habitats in urban forests [32–34]. However, strategies and tools can vary, and research methods require extensive expertise and are difficult to share among geographies [35,36]. Overcoming these disciplinary divisions is key to ensuring that biodiversity and wildlife are included in advancing the field of urban forestry [37]. Connecting urban forest structural variables with their subsequent impact on wildlife, even when highly simplified, promises a chance to provide practitioners with actionable recommendations. In this review, we present lessons learned from this endeavor to use i-Tree's urban forest assessment methods to understand the contributions of urban forests to wildlife habitat and diversity (Figure 1). The initial wildlife habitat models focused on birds because of their role as bioindicators, coupled with the wealth of information available about their natural history [38] and available i-Tree data from the northeastern US. In doing so, we share reflections from the theoretical to the practical on connecting methods and datasets across disciplines and integration with an applied, operational program like i-Tree.

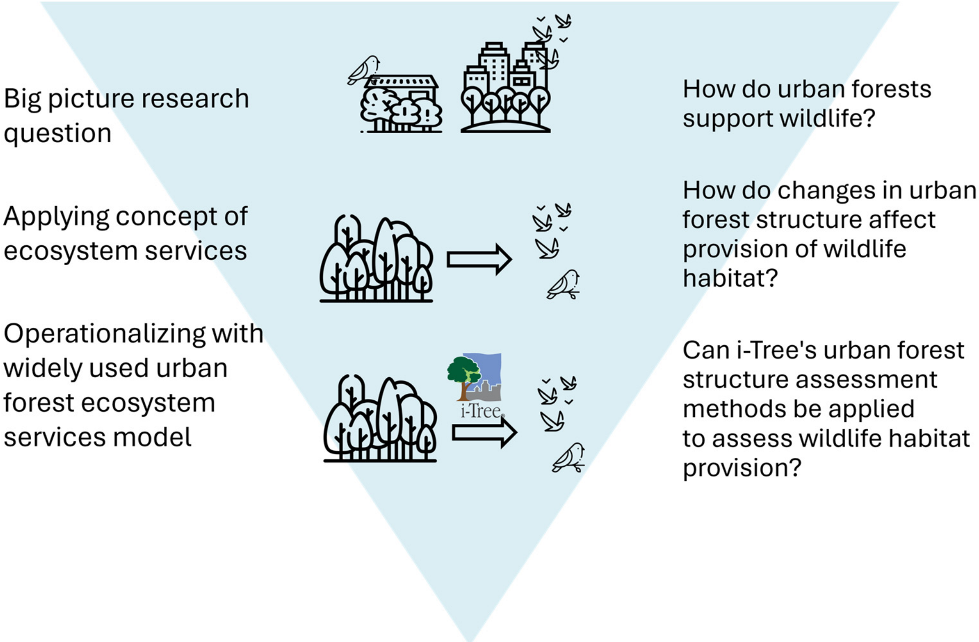

Figure 1. Theory of change for how i-Tree Wildlife addressed the fundamental research question "How do urban forests support wildlife?" (Credit: flaticon.com).

2. Background of Wildlife and the Urban Forest

The seminal 1973 US Forest Service publication "Invite wildlife to your backyard" [39] marked a shift from managing game species in wildlands to recognizing the importance of managing nongame species in suburban and urban ecosystems. The publication also inspired a new field of wildlife and biodiversity research. From the mid-1970s to the 2000s, urban wildlife and biodiversity research focused on distribution patterns along urban gradients, using distance to the urban center or the amount of impervious surface as urban metrics, often from a single region and predominantly conducted in forest patches and public spaces [40–42]. This approach primarily engaged traditional ecological methodology and was largely observational to assess the ecological structure of habitats and communities and the function of these systems. Studies from different ecoregions in North America, Europe, and Australia concluded that in more built-up and urban areas, bird diversity decreased, yet density (i.e., number of individuals) increased, while in rural areas, the opposite patterns occurred [43,44]. These results supported the emphasis on urbanization as a negative disturbance and urban landscapes as non-habitat areas. However, as indicated in the 1973 USDA Forest Service publication, elements within the urban matrix, ranging from individual trees to small residential yards, in addition to large intact forest patches, have the potential to support wildlife and biodiversity [45,46].

By the mid-2000s, urban wildlife research broadened to examine how urban wildlife and biodiversity enhance quality of life and other ecosystem services for urban and suburban (human) residents, and in turn, the integral role humans play in shaping urban ecosystems [5]. The two urban National Science Foundation-funded Long Term Ecological Research (LTER) sites (Phoenix and Baltimore) spear-headed this shift in urban ecological research (e.g., [47,48]). In light of the potential of greenspaces broadly and biodiversity specifically to support ecosystem services for the millions of residents who live in urban and suburban areas, some urban wildlife research shifted towards identifying how to better manage urban greenspaces as wildlife habitats [49–52]. Within any type of greenspace, there is considerable variation in management decision criteria (e.g., tree removal, native plantings [53–55]) and management goals (i.e., regarding aesthetics, ease of maintenance, and safety [56]) that can have far-reaching implications on habitat quality for wildlife. For example, modifying tree-pruning schedules to benefit cavity-nesting birds and leaving dead trees for habitat, when they pose minimal or no risk, can support wildlife populations [53]. These various management practices result in heterogeneous patches of urban greenspace that support a range of both generalist and specialist native species, as well as non-native and invasive species [45,57–60].

Urban forests and urban greenspaces consist of a diversity of plant communities, and their configuration can vary from an individual tree to forest patches. Plants include ornamental, native, non-native, and invasive species [61], with birds responding to these different plants in unique ways. For example, research from the Washington DC metropolitan area demonstrated that Carolina chickadees (*Poecile carolinensis*) spent more time foraging in neighborhoods with at least 70% native plant biomass because of the strong relationship between native plants and their preferred insect prey items [54,62]. Denser and larger street trees in Los Angeles attracted a higher percentage of foraging birds, with strong preferences for both native and non-native species [63]. When urban forests structurally resemble the wildlands they replace (i.e., similar heights and abundance of different types of vegetation), they can support native bird communities [64,65]. And finally, different land-use types throughout the urban matrix (e.g., residential yards, urban parks, and street trees) support distinct species assemblages [60,66,67], though their importance might shift across seasons [68]. These and other studies have documented how birds and other wildlife species respond to the density and structure of the urban forest and provide support for how the urban forest provides wildlife habitat.

The vast majority of urban bird studies have been limited in scope, either focusing on a single species (e.g., [54]), or within a single city (e.g., [59,69], but see [70–72]). Studies conducted at continental scales that investigate multiple taxa are necessary to address the generalizability of biodiversity patterns [73] and to build management recommendations. Empirical studies allow for replication across ecosystems (e.g., deserts and forests) and consider how several factors, such as the amount of impervious surface, tree canopy cover, and management practices, shape bird communities [74]. However, the amount of coordination needed for continental or even global studies is frequently prohibitive. Thus, developing predictive models that can assess existing bird habitat quality for multiple species while identifying opportunities for improving habitat conditions represents an important contribution to habitat conservation. Given the strong relationships between birds and the urban forest, particularly the features captured in the i-Tree Eco plot data collection protocol, it is possible to use urban forest structural datasets to calculate the overall bird habitat suitability for a city or a delineated urban forest assessment project, and the habitat suitability for different types of land-use (e.g., residential, commercial, and parkland) for each bird species [38]. Bird habitat suitability indices based on local data inputs could enable researchers and managers to create and quantify targeted assessments and detailed predictions, and guide land management decisions that support bird habitats. They could also illustrate trade-offs among wildlife species as urban forest structure changes.

3. Developing Models and Operationalizing the Habitat Suitability Index

In 2014, Lerman and colleagues [38] developed habitat suitability index (HSI) models for nine species and integrated them into the publicly accessible urban forest assessment tool, i-Tree Eco (Figure 2). In 2025, the i-Tree Wildlife module expanded to include three additional HSI models for a total of 12 species observed throughout the northeastern and midwestern United States (see Supplementary Materials for three additional species accounts). We selected these species based on specific criteria so they can serve as representatives for other species with similar life history traits or conservation status. We categorized birds into different foraging and nesting guilds, focusing on guilds reliant on forests [41]. The species list includes cavity and open cup nesters, species nesting high in the forest canopy, and those reliant on shrubs and early successional habitat, including species foraging throughout different canopy heights, on bark, and on the ground. Some species specialize in insects, while others have a more generalized diet. We included species with a Partners in Flight (PIF) conservation designation, which ranks a species' conservation vulnerability based on global population, population trends, and threats to breeding populations. Species with a high PIF score have targeted conservation initiatives [75]. We also included two non-native species: house sparrow *(Passer domesticus)* and European starling (*Sturnus vulgaris*). Although all species have unique and sometimes nuanced habitat requirements, we can generalize some aspects and use the habitat suitability indices for some of our 12 species to assess habitat suitability for other forest-dependent species. For example, the red-bellied woodpecker (*Melanerpes carolinus*) requires some deadwood for excavating nests, similar to other woodpeckers like the downy woodpecker (*Picoides pubescens*) and hairy woodpecker (*Leuconotopicus villosus*), and thus, parts of the red-bellied woodpecker HSI could be extended to these other cavity-nesting species. By including two non-native species that might outcompete native species [57], the model outputs could also provide guidance on how to deter some species based on their habitat requirements. For more details about the model building, validation, and uncertainty quantification, please refer to [38].

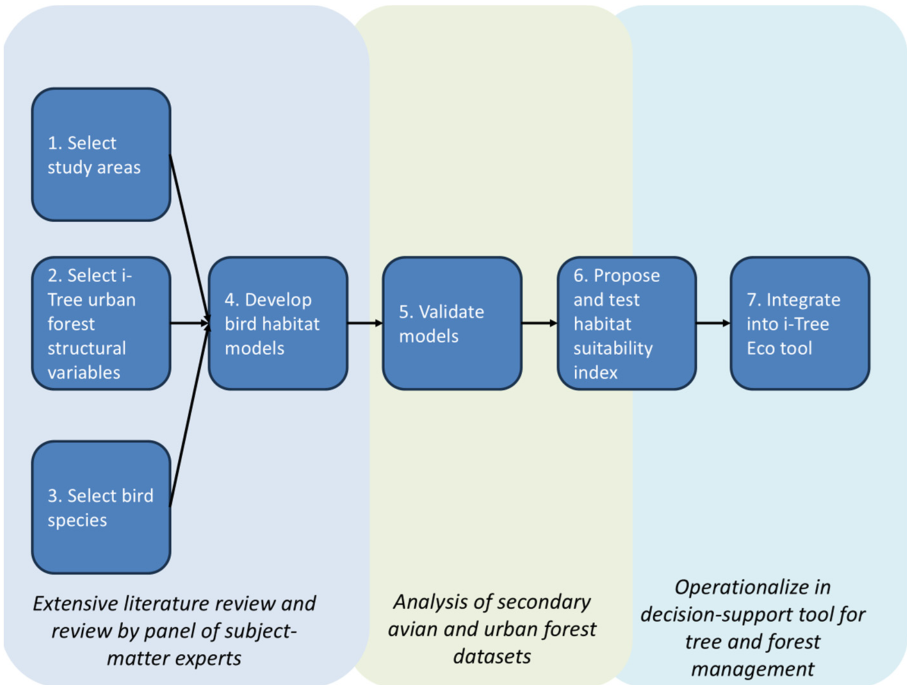

Figure 2. Approach to developing the habitat suitability index [38] and operationalization for practitioner users in the i-Tree Eco tool.

To date, the original nine habitat suitability models have been incorporated into the i-Tree Eco tool. Although the geographic scope for building the models was limited to the northeastern US, the selected species have a broad geographic range, and thus, the models can be and have been applied in different regions (e.g., Michigan; Table 1) when i-Tree urban forest data exist. The modeling approach follows an established protocol developed by Tirpak and colleagues from the midwestern US [76–78], where they integrated natural history information with the US Forest Service Forest Inventory & Analysis program's Nationwide Forest Inventory. Since the publication of the i-Tree bird habitat models, other urban bird studies have followed similar habitat assessments (e.g., [54]). In Santo Domingo, Dominican Republic, research linked city-wide bird surveys with i-Tree plots to expand the geographic scope of the tool (Arendt et al., in review). These and other examples demonstrate the utility and feasibility of replicating the modeling process in other regions using the same i-Tree urban forest assessment metrics. Integrating additional bird species, as well as other taxa (e.g., insect pollinators and mammals), has potential, given their strong associations with urban forests [45,79], coupled with existing natural history information.

Table 1. "How well does my urban forest support birds?" Example output report for an i-Tree project in Grand Rapids, Michigan, USA, from 2011. The suitability index (SI) ranges between 0 and 1, whereby a score of 0 indicates an i-Tree plot has unsuitable habitat conditions with or without trees, i.e., a strong likelihood the species is not present, whereas a score of 1 indicates the habitat conditions have a strong likelihood of supporting the species. The Index Change Due to Trees calculates the relative change (absolute value divided by SI with trees) and the absolute change when a plot includes trees.

	Suitability Index		Index Change Due to Trees	
Species	**With Trees**	**Without Trees**	**Relative (%)**	**Absolute**
American Robin	0.552	0.549	0.558	0.003
Baltimore Oriole	0.288	0.052	82.122	0.237
Black-capped Chickadee	0.223	0.062	72.051	0.161
European Starling	0.271	0.268	1.085	0.003
Northern Cardinal	0.272	0.289	−6.384	−0.017
Red-bellied Woodpecker	0.239	0.02	91.694	0.22
Scarlet Tanager	0.012	0	97.005	0.011
Wood Thrush	0.074	0	99.547	0.074

The inclusion of assessing wildlife habitat suitability in a practitioner-level tool such as i-Tree Eco demonstrated the feasibility of linking forest management tools with bird conservation planning. i-Tree Eco was designed as a quantitative tool, allowing users to conduct analyses and estimate multiple benefits using data on their own urban forest. Adding bird suitability data to this urban forest assessment tool could enable users to develop quantitative urban forest management targets, rendering plans that prioritize biodiversity more actionable [18]. The inclusion of a wildlife module in i-Tree Eco also expands the scope of the tool by assessing another output or beneficiary of the urban forest, in this case, birds. Having detailed information about bird species supported alongside ecosystem service estimates, such as pollutants removed, carbon dioxide absorbed, and stormwater intercepted, can provide science-based information for enhancing urban biodiversity and addressing other urban greening goals [23].

To fully operationalize the habitat suitability model outputs, framing the models within the context of how urban foresters operate is essential. For urban foresters, outputs can answer the question "How well does my urban forest support birds?" (Table 1). To answer this question, the i-Tree models calculate a suitability index that includes tree variables for a particular species, and the suitability index that excludes tree variables for that species (i.e., "with" and "without" trees), to capture the contributions of trees, regardless of their structure or composition, to the habitat for a particular bird species within a city. Based on these indices, the assessment calculates the benefit of trees for each species at each plot/stratum by calculating a relative change (%) and absolute index change due to trees being present. For example, trees in Grand Rapids, Michigan, US, improve Baltimore oriole (*Icterus galbula*) habitat by 82% compared with locations without trees (Table 1). Though this approach aligns with other modeling efforts in the i-Tree tool (e.g., calculating the tree ecosystem services related to stormwater runoff), this framing is not ideal for decision-making when the interest focuses on *how* to improve habitat.

A question closer to the decision-making context asks, "What are specific urban forest structure goals for supporting birds?" (Table 2). To address this question, linking suitability indices of different land-use strata with optimal suitability, practitioners can set targets in management plans, such as how much to increase tree canopy cover or how many trees with deadwood to conserve (Table 2). For example, based on the HSI for the red-bellied woodpecker, increasing canopy cover from 20% to 35% increases the suitability of the urban forest threefold (from 0.3 to 0.9; Table 2), and provides guidance for other species with similar tree canopy requirements [38]. At its core, i-Tree Eco is a science delivery tool, and thus, having intentionality on how results are shared can increase the likelihood of tool use. Although Table 2 addresses this issue, it is not included in the current i-Tree Eco reports. Adding these types of results would increase the tool's utility in creating actionable information from the HSI models and forest inventory data. As a caveat, the habitat suitability models demonstrate the potential habitat conditions for supporting a particular species by providing a threshold, and not a guarantee of occurrence. The habitat variables might not represent the most informative variable for suitability, yet they still contribute to habitat selection. Plus, the i-tree variables can be manipulated by urban foresters. Thus, the HSI models are best used for guidance and conservation planning.

Table 2. "What are specific urban forest structure goals for supporting birds?" An example of the suitability indices for the red-bellied woodpecker, at the city-level, from two different cities (Philadelphia, PA, USA, and New York, NY, USA) and within two different strata (i.e., residential and park land-uses) for each habitat variable. The shaded row represents the optimal values for each variable, i.e., when suitability is 1. Asterisks indicate the specific habitat conditions for a variable that falls within optimal levels. Variables that fall below optimal values, e.g., canopy % for residential lands in both cities, provide a starting point for developing management goals. For example, targeting an increase of ~25% canopy cover in residential areas in Philadelphia is one part of improving habitat suitability for the species.

Red-Bellied Woodpecker	Suitability Index	Canopy % [1] (0.04 ha)	Large Tree Density [2] (0.04 ha)	Basal Area [3] (m^2/ha)	Deadwood Abundance [4] (0.04 ha)
Study Area: Philadelphia	0.39	17.6	2.41	12.62 *	4.75
Residential land-use	0.20	12.5	0.68	1.91	1.26
Park land-use	0.70	75.5 *	5.11	10.91 *	9.06
Optimal		**35%–62%**	**>6**	**8–14**	**1–3**
Study Area: New York	0.17	23.2	1.03	5.51	0.49
Residential land-use	0.15	19.5	0.63	1.47	0.3
Park land-use	0.30	36.0 *	2.12	4.57	0.85

[1] Canopy % is the percentage of the i-Tree plot covered by tree canopy. [2] Large tree is the total number of trees >23 cm DBH within the i-tree plot. [3] Basal area calculates the basal area of all trees >6 cm DBH. [4] Deadwood is the total number of trees within the i-Tree plot classified as "Fair", "Poor", "Dying", or "Dead".

4. Challenges and Opportunities

Integrating wildlife habitat models into i-Tree Eco presented an opportunity to use a platform familiar to urban foresters who make management decisions that have implications for wildlife habitat. However, even after developing the models, challenges exist, e.g., balancing the complexity of the models with the simplicity of reporting, and how to expand the number of species included and the geographical scope.

Building the wildlife habitat module extended the reporting capacity of i-Tree Eco for US users. However, there were several limitations to the model-building process. First, developing a habitat suitability index for each species is time-consuming, taking approximately 80 h per species. The process included an extensive literature search to identify studies that quantified habitat relationships with a specific metric, e.g., nest success. Fortunately, birds are very well-studied, and extensive information exists. However, this also represented a challenge because of the excessive amount of information to search. Furthermore, the literature often focuses on a single species, with habitat relationships for a particular species (e.g., [80]). Although this provides detailed information for a particular species, it translates to building one habitat suitability index at a time. Once a study has been identified as having habitat information linked to a metric of success, the specific habitat features and the scale in which they were collected might not match the urban forest structural variables or plot sizes (in our case, an 11.2 m radius i-Tree Eco plot); e.g., see studies. on the wood thrush (*Hylocichla mustelina*) home range and roosting areas [80,81]. Habitat measurements include vegetation density and forest structure using LiDAR to address the specific hypothesis, but do not easily translate to field-collected structural variables. This challenge is compounded by the need to identify multiple studies per habitat variable to account for variation, and the need to replicate the process for multiple habitat variables.

Augmenting the scarcity of published datasets with estimated values can fill these data challenges. For example, when building the HSIs for i-Tree, iterative values were supplemented, which improved the predictability of the habitat models. These iterative values were then reviewed by a panel of experts, which allowed for the models to be revised according to recommendations [38]. Soliciting experts can also address the labor-intensive process, which is difficult to scale. For example, in Australia, the Biodiversity Sensitive Urban Design (BSUD) framework solicited expert knowledge to assist with urban planning. Experts helped estimate habitat and connectivity requirements for woodland birds. The baseline data was integrated into urban planning actions, ultimately benefiting biodiversity [82].

Once the studies had been identified, variables selected, and the habitat suitability models developed, the models then required validation [38]. Validating the habitat suitability models required datasets that included bird survey data co-located with i-Tree plots. At the time, to our knowledge, these data only existed in Baltimore, MD, as part of the Baltimore Ecosystem Study Long-Term Ecological Research (BES LTER) program [38,83,84]. Harnessing support from birders [31] to conduct additional surveys to help build and validate models holds potential. However, coordinating data generated by thousands of citizen scientists requires considerable resources and expertise. Although robust models depend upon the underlying data used for building habitat relationships, the unvalidated models still have value [85], and can serve as a starting point for understanding how birds might respond to different urban forest management practices.

Geographical challenges also existed with the model-building process. The i-Tree user (e.g., urban forester, urban planner, and the public) is focused on local information about a specific urban forest or urban trees. Because of the challenges of matching the ornithological literature with urban forest structural variables, the studies available for building the habitat suitability models might have a geographical mismatch. For example, the red-bellied woodpecker habitat suitability model relied on studies from Ontario, the Midwest, and southwestern Virginia [86–88], though they were applied to ten northeastern US cities [38]. Although it is likely that the urban forest composition and configuration amongst these different regions have some similarities [89], it is unclear how consistent the habitat relationships are across a species' breeding range. Ornithologists do not have a standardized way to collect habitat data, and oftentimes the variables are particular to a specific species or research question [90,91]. However, establishing a set of consistent variables to collect, e.g., using variables from established urban forest monitoring protocols for habitat assessments and habitat relationships, can further address these challenges [92,93].

5. Conclusions

The i-Tree Wildlife module demonstrated how to model habitat suitability based on urban forest structure. Additional opportunities exist for further integration of other wildlife data with urban forest datasets and tools. This integration can increase our understanding of habitat suitability relationships alongside tree and urban forest assessments. For example, integrating landscape-scale habitat variables, e.g., the US Forest Service Tree Canopy Cover datasets [94] or the U.S. Geological Survey's National Land Cover Database [95] with citizen science wildlife monitoring programs such as eBird (a Cornell Lab of Ornithology citizen science repository for birders' species list [96]) and iNaturalist, has the potential to uncover coarse relationships between available habitat and bird presence at a continental scale [97,98]. The InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) tool also assesses the ecosystem services in urban systems. Integrating landcover data with pollinator habitat studies, InVEST developed a pollination model to identify areas that would benefit from habitat improvement efforts. However, their models are based on spatial greenspace availability data, not forest structure and composition. The US Forest Service's Urban Forest Inventory and Analysis (FIA) program and other urban forest inventories with structural variables have strong potential for informing additional HSIs [61]. Finally, i-Tree's other ecosystem service models have been integrated into other public tools, e.g., the American Forests' Tree Equity Score (www.treeequityscore.org), as well as industry tools by private companies in the US and abroad.

Future research that builds from the understanding of bird habitat and urban forest relationships can further address how to improve decision support tools [99]. Addressing the challenges of geography, labor intensiveness of model building, capacity issues, input data, and how to generate results that users can operationalize are key factors to consider. Participatory evaluation of future user interfaces and reporting outputs by both urban foresters and wildlife managers could also aid in the effective use of the results in practice [100]. Here, we shared generalizable findings and key takeaways from the i-Tree Wildlife endeavor. Ultimately, the improvement of tools, e.g., i-Tree, can assist practitioners who aim to manage healthy and productive urban forests that benefit people and wildlife.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f17050620/s1. Refs. [101–115] are cited in the Supplementary Materials.

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