





Review

Do Review Papers on Bird–Vegetation Relationships Provide Actionable Information to Forest Managers in the Eastern United States?

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Abstract: Forest management planning requires the specification of measurable objectives as desired future conditions at spatial extents ranging from stands to landscapes and temporal extents ranging from a single growing season to several centuries. Effective implementation of forest management requires understanding current conditions and constraints well enough to apply the appropriate silvicultural strategies to produce desired future conditions, often for multiple objectives, at varying spatial and temporal extents. We administered an online survey to forest managers in the eastern US to better understand how wildlife scientists could best provide information to help meet wildlife-related habitat objectives. We then examined more than 1000 review papers on bird–vegetation relationships in the eastern US compiled during a systematic review of the primary literature to see how well this evidence-base meets the information needs of forest managers. We identified two main areas where wildlife scientists could increase the relevance and applicability of their research. First, forest managers want descriptions of wildlife species–vegetation relationships using the operational metrics of forest management (forest type, tree species composition, basal area, tree density, stocking rates, etc.) summarized at the operational spatial units of forest management (stands, compartments, and forests). Second, forest managers want information about how to provide wildlife habitats for many different species with varied habitat needs across temporal extents related to the ecological processes of succession after harvest or natural disturbance (1–2 decades) or even longer periods of stand development. We provide examples of review papers that meet these information needs of forest managers and topic-specific bibliographies of additional review papers that may contain actionable information for foresters who wish to meet wildlife management objectives. We suggest that wildlife scientists become more familiar with the extensive grey literature on forest bird–vegetation relationships and forest management that is available in natural resource management agency reports. We also suggest that wildlife scientists could reconsider everything

from the questions they ask, the metrics they report on, and the way they allocate samples in time and space, to provide more relevant and actionable information to forest managers.

Keywords: forestry; silviculture; forest wildlife–habitat relationships; evidence-based practice; implementation gap; research relevance; synthesis; knowledge exchange; science–practice

1. Introduction

Sustainable forest management that considers wildlife populations requires close collaboration and efficient knowledge exchange between forest managers and wildlife scientists [1,2]. In the United States (US), several landmark environmental laws provide pathways for this exchange that result in frequent, systematic analyses of the effects of management on wildlife species and their habitats. For example, the National Environmental Policy Act (NEPA) of 1969 requires that all federal agencies whose actions may adversely impact the natural and human environment prepare an Environmental Impact Statement (EIS) [3]. An EIS requires management agencies to describe their different management actions specifically and to assess potential impacts on species and natural and human communities. An EIS provides a structured approach for agencies to propose multiple alternative courses of action. Management alternatives are then subjected to analysis, peer review, and public comment. At the end of this process, the management agency selects a preferred alternative from the full set of evaluated alternatives, which becomes the foundation for future management planning and implementation. NEPA makes the comparison of different management alternatives a fundamental requirement for management and conservation planning in the US.

The Endangered Species Conservation Act (ESA) of 1973 provides additional protections for individual species and their habitats [4]. The ESA requires species status evaluation at the spatial scale of a listed population’s entire geographic range, organized by recovery units, and the temporal scale of the foreseeable future. These scales of evaluation encourage long-term, landscape or regional planning efforts. The ESA also requires consultation between management agencies or private landowners and the US Fish and Wildlife Service (USFWS), when specific actions, often at the project or program scale, may affect listed species.

Finally, the National Forest Management Act of 1976 (NFMA) requires that management plans written by the US Forest Service (USFS), the largest forest management agency in the US, comply with NEPA and that selected management alternatives maintain viable populations of existing native vertebrates on National Forests [5]. These three pieces of legislation, among others, require any proposed, large-scale resource management activity in the US to consider impacts on species, habitats, ecosystems, and the human environment at spatial scales from individual projects to large landscapes. See Chapter 1 of Morrison et al. (1998) [6] for a more detailed history of the impacts of environmental law on wildlife conservation in the US.

Beyond federal lands, forest management planning often occurs at smaller spatial extents to meet the diverse objectives of states, counties, and private landowners; including the improvement of wildlife habitat [2,7]. In some cases, objectives associated with sustaining native biota are linked to best management practice guidelines to protect water quality and wildlife resources during timber harvest or other forest management activities [8,9]. Similarly, forest certification programs often include criteria associated with maintaining critical forest habitats and sustaining populations of threatened and endangered species [10]. Over the past century, active coordination of forest management activities for wildlife-related objectives has often focused on state and federal lands [11]. However, more than half of the forest lands of North America are privately owned, with >11 million private ownerships, 95% of which are classified as family and individual ownership, with average holdings of 98 acres [12]. In parts of the eastern US, family and

individual private forest ownership dominates forested landscapes. For example, in Pennsylvania, 68 percent (11.5 million) of 16.9 million acres of forest land is privately owned by 736,000 individual, non-industrial, private land owners [13]. Consequently, conservation action on private forests is essential to improve regional habitat conditions for birds [14,15]. Landowner assistance programs associated with the US Department of Agriculture's Farm Bill [16] provide technical and financial assistance to non-industrial private landowners for the development of forest stewardship plans to meet financial and other objectives (e.g., USDA Forest Service's Forest Stewardship Plan [17] program and Natural Resources Conservation Service's Environmental Quality Incentives Program [18]). The NRCS administers two different landscape-scale conservation planning and implementation efforts, the Working Lands for Wildlife [19] initiatives and Regional Conservation Partnership Program [20] that link high-priority wildlife habitat and forest management with technical and financial assistance to private landowners. Each of these forest management planning and implementation programs can benefit from clearly presented information on wildlife habitat needs that is explicit enough to allow for implementation in the context of the multiple, and sometimes conflicting, objectives for forest management at various spatial and temporal scales [21,22].

Each of the landmark environmental laws and many of the planning processes described above require use of the "best-available science" to develop and evaluate different management alternatives and their potential effects on species, habitats, and ecosystems. In response to the environmental laws of the late 1960s and early 1970s, the USFS hosted a series of workshops between 1975 and 1985 to synthesize information on the effects of different types of forest management on wildlife for numerous forest ecosystems across the US [23–27]. During the same period, the USFS published two foundational documents that describe the major forest types [28] and silvicultural systems [29] in the US. Additional influential workshops and publications from the following decade added to this foundation and the study of forest wildlife–habitat relationships was broadly developed in forest management contexts across the US [30–41]. Literature from this era frequently reinforced the idea that forest managers and wildlife scientists should speak the same language, measure the same quantities, and work at the same scales. Plot-based methods for measuring vegetation characteristics at bird sampling locations were widely adopted by ornithologists and forest ecologists, facilitating the comparison of avian data collected at nest, territory, or home range levels of organization with vegetation data collected at the scale of plots within stands [42,43]. This opened the door for wildlife scientists to present forest wildlife management objectives as desired future conditions, at stand scales, that could be integrated directly into the comparison of forest management alternatives required by law [44–46]. This period of wildlife–habitat relationships research is synthesized in the text book "Wildlife-Habitat Relationships" and robust regional applications were developed in the form of comprehensive wildlife–habitat matrices and management typologies in the Pacific Northwest and the Northeastern US [41,47,48].

By the early 1990s, the term "habitat" was ubiquitous in wildlife science, enough so that arguments over the usage of this word and related terms became its own subtopic [49–51]. At the center of this "controversy" was the fact that the word habitat was being used two very different ways. First, to describe vegetation characteristics that can be identified independent of any particular wildlife species (e.g., coniferous forest habitat, oak habitat, or early successional habitat) and second, to describe the specific set of resources that are necessary for the reproduction and survival of a given species (e.g., nest tree preference, food availability, or roosting areas). Arguments over which of these two usages were "correct" distracted from the fact that either paradigm can be useful, depending on context [52]. In fact, these two different usages are easily integrated into a single, three-level hierarchical framework: (1) forest type, (2) stand age/seral stage, (3) within-stand habitat elements, that is compatible with evaluation of management effects on forest wildlife [30,47,53]. For example, a species may have its highest reproductive rates in a given forest type, within a specific stand development stage, because this combination is most likely to provide them

with the specific resources, like abundant soft mast in regenerating clearcuts or abundant cavity trees in older forests, that they need for successful reproduction and survival. A research emphasis on the measurement and description of within-stand habitat elements, particularly structural and compositional conditions that can be manipulated by foresters, stratified by forest type and age class, is compatible with the development of silvicultural guidelines for any forest type. It is also compatible with many different approaches to landscape scale forest management planning.

Development of wildlife habitat relationships matrices for use in forest management contexts was concurrent with an explosion of studies using multivariate statistics, where vegetation plot data were often used to describe bird community dynamics along environmental gradients [31,54]. This period resulted in a disconnect between results generated by wildlife research and forest managers, since summary measurements of forest characteristics that could be directly manipulated by foresters were now expressed as abstract scores for dimensions, or “components”; combinations of numerous measured variables that explained the most variance in the data [55,56]. Studies with graphical presentations of multivariate analyses often failed to express results in ways that could be integrated directly into forest management planning or stand-based silviculture. During the same period, the number of studies investigating habitat selection grew exponentially [33,57–59] and articles on multi-scale habitat selection became common [37,60–62]. The discipline of landscape ecology emerged; providing another large set of metrics related to the process of habitat fragmentation, accompanied by new arguments about theory, methods, and the interpretation of results [63–69]. There was an increase in the availability of remote sensing datasets, but these lacked the thematic resolution desired by forest managers (e.g., coarse classification of cover types to deciduous, evergreen, or mixed). Extensive use of these GIS datasets to generate species distribution models, increased the number of publications presenting information that was not easily incorporated into operational strategies for forest managers [70–72].

Throughout this expansion of conceptual and methodological approaches toward the collection and analysis of data in wildlife science, authors have noted the presence of communication gaps between forest managers and wildlife scientists as both professions became increasingly specialized [73–75]. The exponential increase in the number of scientific journal articles published annually has made this evidence base more complex, harder to assimilate, and less likely to be used to solve real-world problems in forest management. This has led to calls for new sub-disciplines like translational ecology or structured decision-making to facilitate communication between scientists and managers whose ways of thinking and communicating have diverged to the point where this translation may be necessary [76,77]. Another approach to dealing with a rapidly expanding evidence base is the application of systematic review methodology and meta-analyses to integrate results from multiple studies; providing generalized inference about specific forest management topics [78–85]. However, some ecological problems are both spatially and ecologically specific, with low transferability across ecological contexts [86,87]. Consequently, pooled study analyses that do not control for variability in study systems may not provide the type of regionally specific information that managers need to inform specific planning or implementation tasks [88].

As one critic of systematic reviews commented, “managers... simply don’t have time to read the literature, however rigorous” [89]. This comment probably resonates deeply with most natural resource managers and suggests a need to more carefully consider new (or revisit old) approaches to knowledge exchange between wildlife scientists and forest managers [74,90,91]. Regardless of how information transfer occurs, we believe it would be helpful for wildlife scientists to examine their connections with forest managers to ensure that they are providing information that is more directly relevant to management operations.

Herein, we focus on a common problem of the science–practice interface [92] in the context of forest wildlife habitat management. That is, are wildlife scientists providing information that is both relevant and specific enough to be actionable in real-world,

evidence-based forest management contexts? To meet this objective, we designed and administered a survey to forest managers in the eastern US and asked them to: (a) describe which types of information they find most professionally relevant, and (b) whether or not the information they receive from wildlife scientists is relevant enough to inform their operations. Based on our summary of survey results, we provide examples of several review papers that provide information relevant to forest managers. We located these examples from a pool of 1173 review papers that we identified during a systematic review of primary research articles on forest bird–vegetation relationships [83]. Since birds are the most speciose vertebrate taxon in the eastern forests of the USA, are plausibly indicators of conditions for other taxa, and are subject to regulation under NEPA and other legislation requiring planning and evaluation, we argue they are a useful and legitimate group to illustrate the conformity of scientific information to the needs of managers and conservationists. Finally, we provide suggestions for how wildlife scientists can better design and communicate research studies so that research on forest bird–vegetation relationships may be more likely incorporated into forest management planning and practice.

2. Materials and Methods

2.1. Survey Instrument

We designed an online survey using Google Forms to acquire anonymous responses from forest management professionals in the eastern United States. Before sending out our final survey instrument, we received feedback on a draft survey instrument from 3 forest management professionals (see Acknowledgments). The survey was a mix of multiple-response questions where respondents could check one or more boxes from a list of options, and open-ended questions that allowed narrative responses. The draft survey instrument (Supplementary S1) and an invitation letter to potential participants (Supplementary S2) was reviewed and approved by the Internal Review Board for research on human subjects at Antioch University (ethics review case number 0308282).

Questions were organized into the following categories: demographic information about participants, spatial and temporal scales of operations, specific forest management activities and applications, metrics for describing forest characteristics, and the use of specific forest type classification schemes. For each multiple response question, we report the percent of respondents that checked a box for each specific response level. For example, when asked to identify their professional role, 46% of all survey respondents identified themselves as a “forest planner” and 90% identified as “foresters”. These proportions sum to greater than 100% because multiple response options could be selected for each question.

2.2. Survey Distribution

Email invitations to participate in the online survey, with a link to the survey instrument, were distributed to many individuals via collaboration with leadership and committee chairs of several different forest management professional societies (see Acknowledgments). For the sake of preserving anonymity of respondents and to assure the professional societies that we would not contact them in the future, we did not request specific mailing lists. As a result, we did not closely control the distribution of survey invitations. For example, we were unable to track how many invitation emails reached potential participants, how many potential participants received invitations from >1 source, or how many times survey invitation emails were forwarded. We coarsely estimate the number of original invitations that were sent via email by each of our professional society contacts to be between 600 and 1000.

2.3. Survey Administration and Screening of Responses

The survey was open from 7 December 2020 through 13 January 2021. Individual survey responses were time-stamped, but no other unique identifiers were collected for participants, given our promise of anonymity. We received 109 unique, time-stamped survey responses. We asked participants to only take the survey once, but had no way of

enforcing this, as we did not collect names or IP addresses. We qualitatively compared answers to multi-response and open text response questions and did not find any records that seemed like they could have come from the same person.

We applied several screening criteria to ensure that survey responses reflected the opinions of professional forest managers. First, we selected for inclusion all records where participants identified their professional role as either a forester, a forest planner, or both, and also included information about professional affiliations. We excluded records of 5 survey responses that were missing professional role or affiliation information or listed uncommon roles or affiliations that occurred two or less times across the full set of responses. Additionally, we excluded 11 responses where professional role was listed as wildlife biologist after learning that the survey had been forwarded to a listserv for threatened and endangered species biologists. The opinions of this group are valuable; however, the goal of our survey was to summarize responses of forest management professionals, not wildlife biologists.

2.4. Summarizing Survey Responses

All data summaries were based on a final pool of 91 unique survey responses, which we believe represented 91 unique individuals. Not all questions were answered by each respondent. For the 12 multiple-response questions in the survey, there was an average of 85 responses (SD = 5.1, min = 73, max = 91). Upon preliminary examination of survey results, we observed that answers to multi-response questions did not differ substantially among survey respondents who identified their professional role as forester, forest manager, or both; or among affiliations. Consequently, survey responses were summarized across all survey participants in aggregate, regardless of role or affiliation. Each multiple-response question was summarized by the proportion of all respondents that selected response levels that were provided as a list of options.

Our survey instrument included 7 open-ended questions that allowed for free text responses (Supplementary S1). Six of these were topically similar to the multiple-response questions. The remaining question allowed foresters to describe the systems they use to classify stands to age, seral stage, or structure classes. We posed this as an open-ended question, since we were unable to locate any standard widely used classification systems for stand age/stage/structure. Since open-ended question responses did not provide enough text for formal structured or unstructured text analysis, we copied all text responses, by question, into a single document and read each individual response. Many of the text responses reinforced results shown for multi-response questions. However, we identified four common topics in text responses that provided additional insight, in our view, to the types of information that forest managers would like to receive from wildlife scientists. We present representative text excerpts for each of these topic area in Section 3.2, lightly edited for grammar and with acronyms replaced with explicit term names. Some text excerpts were shortened by ellipsis for more concise presentation. Complete, un-edited responses are presented in Supplementary S3.

2.5. Searching for Review Papers on Forest Bird–Vegetation Relationships

This paper was conceived during the process of conducting a systematic map of the primary literature on bird species–vegetation relationships in Eastern North America [83]. Details of the systematic map’s review question, study population, search strategy, and screening criteria have been published as a protocol document following the guidelines of the Collaboration for Environmental Evidence [83,93].

During the title-abstract screening stage for this systematic map, we noticed a large number of review papers were returned by our searches and we filed these review papers separately. Additionally, our systematic map search identified 127 books or conference proceedings on topics that were potentially relevant to our primary literature review (Figure 1). We screened all titles in the tables of contents for each of these volumes, and then screened full text versions of potentially relevant individual references, and

extracted all relevant chapters, or individual conference papers, for further review. These steps led to the inclusion of 968 review papers that were identified during our primarily literature systematic map searches for further consideration herein (Figure 1). An additional 232 review papers were identified for potential inclusion in this paper outside of the searches associated with our systematic map of primary literature. This set of review papers includes: (1) references that were identified via alerts from Web of Science, ProQuest, and EBSCO Host search engines, and Google Scholar, based on search strings from our systematic map of primary literature; received after our final systematic search for that project; (2) references identified from the literature cited sections of review papers that were not found via prior searches; (3) references that were identified by coauthors of this review from previous professional experience; and (4) searches of websites of forest management agencies related to the survey of manager perspectives reported herein (Figure 1).

2.6. Eligibility Criteria for Inclusion of Review Papers in Supplementary Appendices

After reviewing responses from survey participants (see Results), we screened a final pool of 1173 review papers to generate reference lists, reported as Supplementary S5 and S6, for articles addressing two major topics of interest to forest managers: (1) bird abundance, occurrence, or habitat use relationships with tree species composition at the thematic resolution of Society of American Forester forest types or dominant tree species; and (2) bird abundance, occurrence, or habitat use relationships with stand structure (using forestry-relevant metrics like basal area, trees per acre, stocking, etc.) or within-stand structural habitat elements (e.g., snags, coarse woody debris, canopy gaps, large trees) (Figure 1, Supplementary S5 and S6). Given the broad spatial extent of many of our review papers (e.g., the entire eastern US, forest types that occur across multiple ecoregions), we did not extract latitudes and longitudes for individual references. Beyond assigning references to Supplementary S5 or Supplementary S6, we did not perform any additional critical evaluation or data extraction from the full set of references reported in Figure 1. Consequently, we do not consider this review to be a systematic map, per se, but rather, an initial attempt to identify review papers with potential relevance to forest managers given their responses to our survey instrument.

We note that the group of review papers evaluated here reflects exclusion criteria that were previously applied during the screening stage of our systematic map of primary literature [83]. For example, eligible references were required to have at least one metric related to bird abundance, occurrence, habitat use, or reproductive performance and at least one vegetation metric related to floristics or structural attributes. References that reported only the presence of an effect, or the strength of an effect, without providing descriptive statistics or quantitative relationships between variables describing the nature of the effect, were excluded, as these did not provide actionable information that could be used to define a desired future condition. Previously, our systematic map protocol defined species as our fundamental biological unit of interest and the breeding season as the temporal extent for our review of bird species–vegetation associations [83]. As such, references were required to report information for one or more eastern North American forest bird species during the breeding season to be evaluated further. References that only reported results for bird species grouping above the species level (e.g., guilds, communities) or during the non-breeding season (winter, migration) were excluded, as were references that only used response variables related to species richness, evenness, or other diversity metrics. Additionally, references that reported only landscape-scale variables (e.g., edge density, percent forest cover within a given neighborhood size), and not information at stand or within-stand scales, were excluded from Supplementary S5 and S6, as survey respondents were clear about their desire for information at stand or within-stand scales. Finally, our systematic map of primary literature covered a broad spatial extent spanning temperate and boreal forests of eastern North America. For this paper, we excluded reviews from outside of the eastern United States.

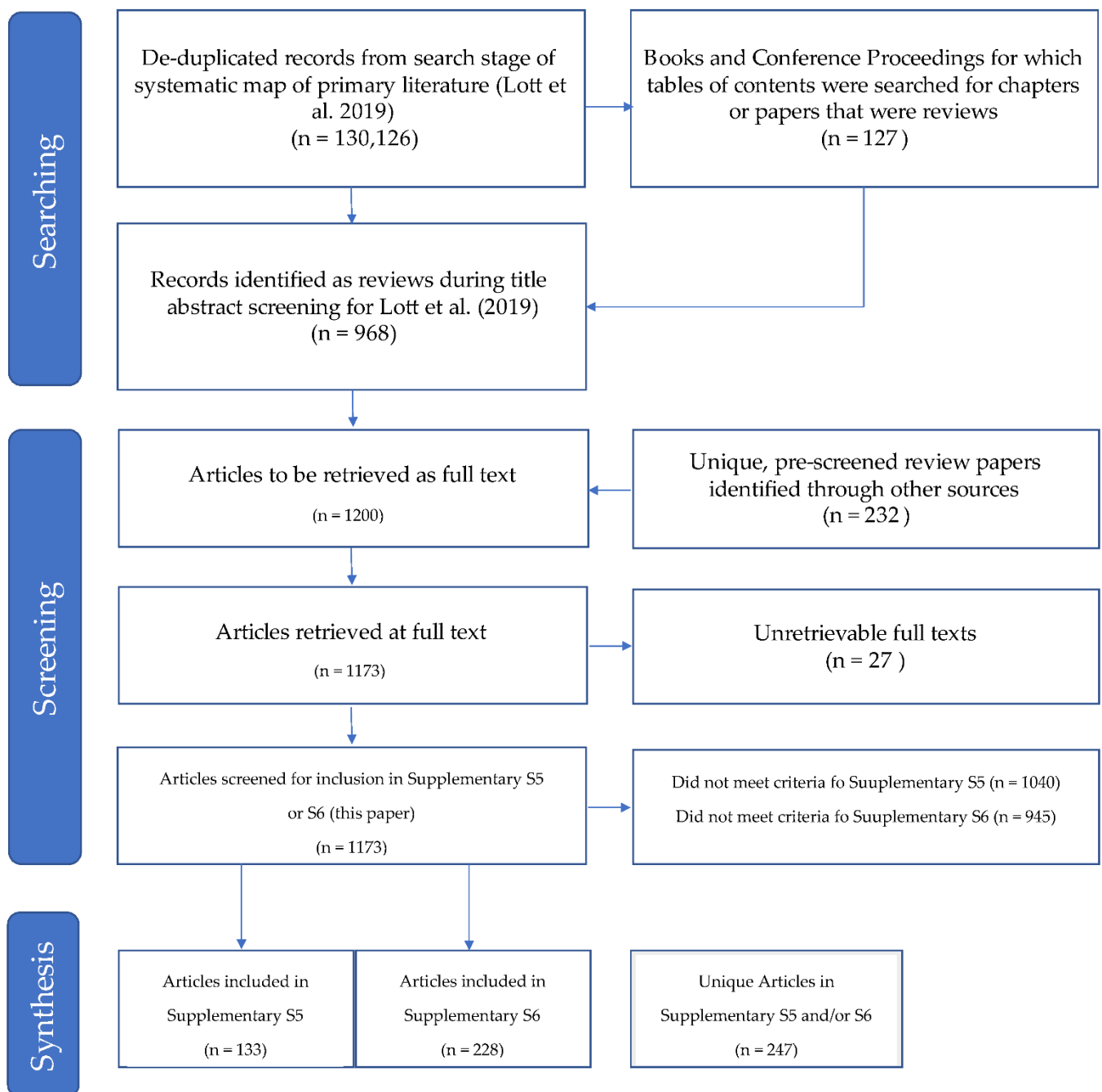


Figure 1. RoSES reporting form for systematic maps (Haddaway et al. 2017) [94] illustrating the number of references found during literature searches; the number of references subjected to title only, title–abstract, and full-text screening; and the number of references that met inclusion criteria for Supplementary S5 and S6.

3. Results

3.1. Answers to Multiple Response Questions

3.1.1. Professional Roles, Affiliations, and Common Activities

We received responses from managers who identified themselves as field foresters (90% of respondents), forest planners (46%), or both (38%). At least 10% of respondents described their affiliations as consulting forester (46%), state agency (31%), federal agency (11%), or extension forester (11%) (Supplementary Figure S4a). We listed five different activities that we categorized a priori as field forester activities and five different a pri-

ori forest planner activities. At least 75% of survey participants selected each of these 10 activities as aspects of their professional responsibilities (Supplementary Figure S4b,c).

3.1.2. Forest Regions and Landscape Sizes Covered by Survey Participants

At least 10% of survey respondents selected working areas from five different forest regions [95]: Mixed Mesophytic (38%), Beech-Maple-Basswood (27%), Northern Hardwood-Red Pine (24%), Southern Mixed (19%), and Northern Hardwood-Hemlock (11%). Less than 10% of survey respondents represented three important eastern forest regions: Oak Hickory (4%), Mississippi Alluvial Plain (2%), and Subtropical Evergreen (2%) (Supplementary Figure S4d). Many survey respondents selected operational landscape sizes of less than 100,000 acres, with 57% of respondents working in landscapes <1000 acres. Larger landscape size bins were less frequently selected as operational landscape sizes for survey respondents (Supplementary Figure S4e).

3.1.3. Spatial and Temporal Characteristics of Data Relevant to Forest Managers

More than 75% of survey respondents cited a need for data on forest characteristics at within-stand (84%), stand (82%), management zone/compartment (82%), or whole forest (78%) scales. Sixty percent of respondents cited a need for data on individual trees and 58% requested data for landscapes larger than a single forest. Far fewer respondents selected a need for statewide (32%), regional (21%), or national (3%) scale data (Figure 2). Respondents were less specific about the temporal resolution of data on vegetation characteristics. Each of the five presented options, from single events to long-term time series were selected by between 39% and 60% of respondents (Supplementary Figure S4f).

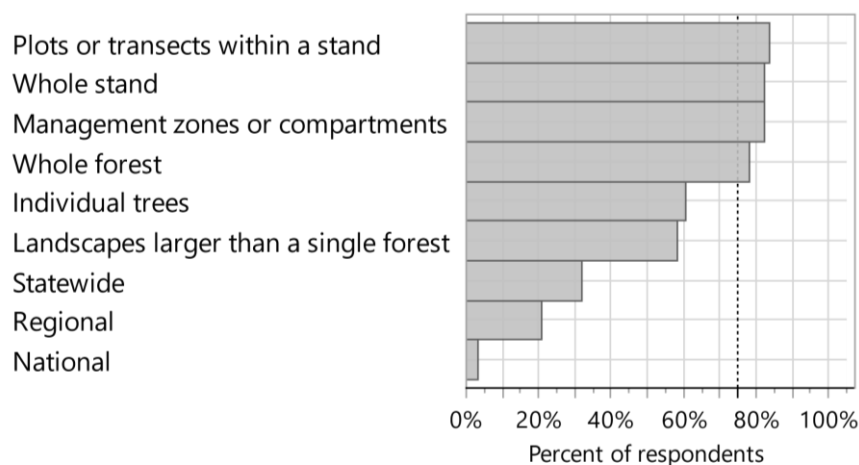


Figure 2. Spatial units for data collection and summary that are relevant to forest managers. Dotted line represents 75% of survey respondents.

3.1.4. Topics for Which Forest Managers Would Like Information from Wildlife Scientists

Between 65% and 71% of respondents said they would like information from wildlife scientists on 6 of the 10 a priori topics that were included as options in our survey. This included general guidance on the value of different wildlife objectives (71%), estimates of how much habitat may be needed for different wildlife species (70%), measuring the amount of existing habitat for different species (67%), tracking changes in the amount of habitat for different species over time (65%), describing wildlife habitat as a specific set of desired vegetation attributes at the scale of plots or stands (67%), or describing wildlife habitat as potential constraints on management operations (66%). Fifty-four percent of respondents desired information on how spatial relationships could be fit into habitat objectives and fewer respondents desired information on species diversity or ecosystem services related to resiliency (Supplementary Figure S4g).

3.1.5. Within-Stand Variables for Which Forest Managers Would Like Information from Wildlife Scientists

We provided a list of 34 within-stand variables for which measurements are taken by wildlife scientists and foresters and asked forest managers to select those for which they would like information from wildlife scientists. Six within-stand variables were selected by >75% of survey respondents, all relating to measurements of trees (Figure 3). Five variables related to canopy cover or understory characteristics were selected by between 60% and 70% of respondents. An additional 21 variables were selected by between 11% and 48% of respondents. This included all variables related to dead wood, mast, and foliage complexity.

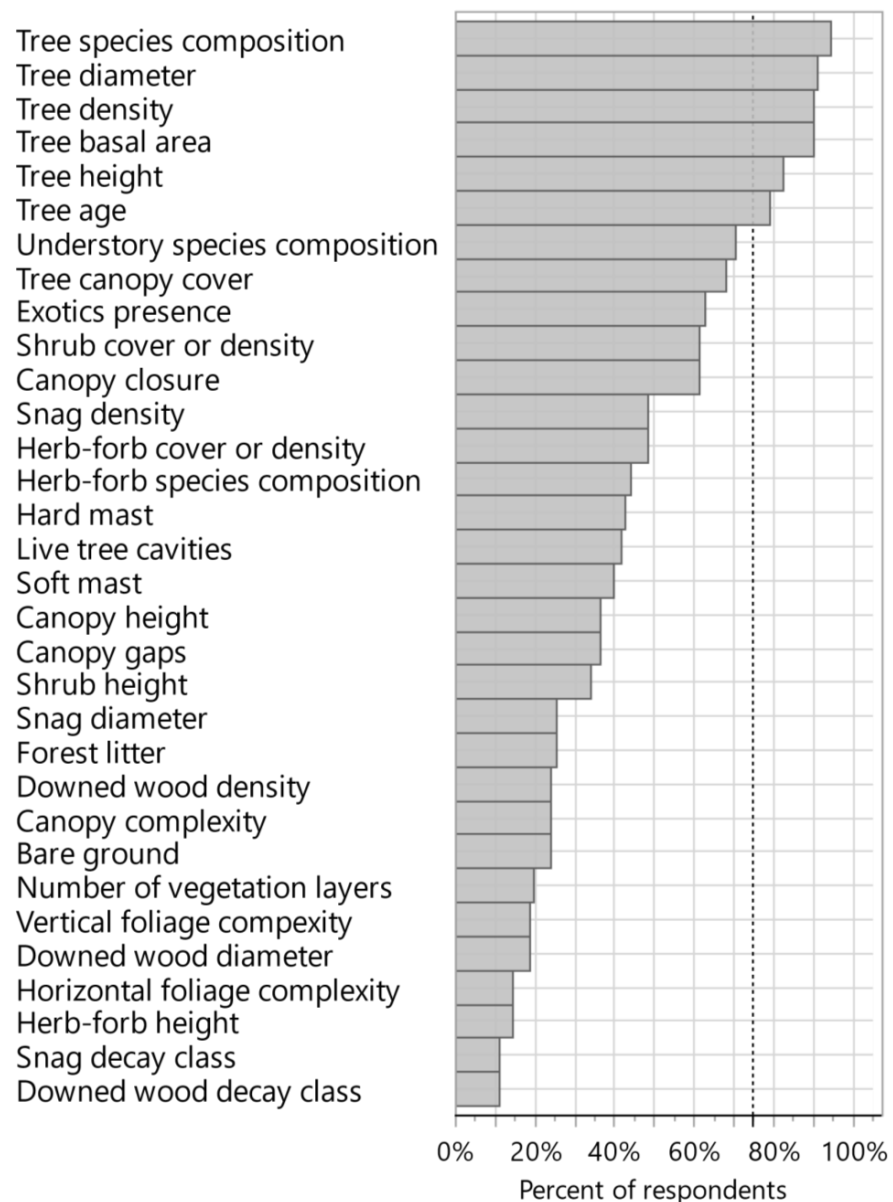


Figure 3. Within-stand variables for which forest managers would like information from wildlife scientists. Dotted line represents 75% of survey respondents.

3.1.6. Stand-Level Variables for Which Forest Managers Would Like Information from Wildlife Scientists

We provided a list of 12 stand-level variables for which measurements are taken by both wildlife scientists and foresters and asked forest managers to select those for which

they would like information from wildlife scientists. Eight of these variables were selected by >70% of respondents, and the remaining four variables were selected by between 25% and 50% of respondents (Figure 4).

Forest type was selected by 90% of respondents. We had a separate multiple response question to collect information on which forest type classification schemes were used by forest managers. We provided a list of 6 a priori forest classification schemes used by either foresters or wildlife scientists and asked managers to select those for which they would like information from wildlife scientists. Four of our a priori options were selected by more than 16% of respondents: Forest Inventory and Analysis (FIA) forest types (57%), Society of American Forester (SAF) Forest Types (33%) [28], standard silvicultural systems (19%) [29], and the National Land Cover Database (16%) [96]. Our two other a priori options were selected by 7% of respondents (Figure 5). However, 23 participants provided written text responses to this question under an “other” response option, reflecting a high diversity of locally applied forest classification systems, seven of these were state-specific cover type schemes that collected information at the same thematic resolution as FIA/SAF forest types (Figure 5). Seventy-seven percent of all survey respondents reported the use of classification schemes that relied on site-based inventories and the assessment of dominant and subdominant canopy trees (Figure 5).

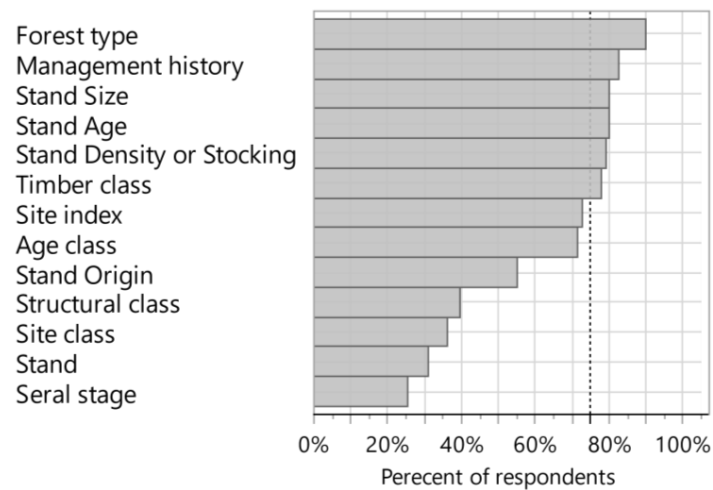


Figure 4. Stand-level variables for which forest managers would like information from wildlife scientists. Dotted line represents 75% of survey respondents.

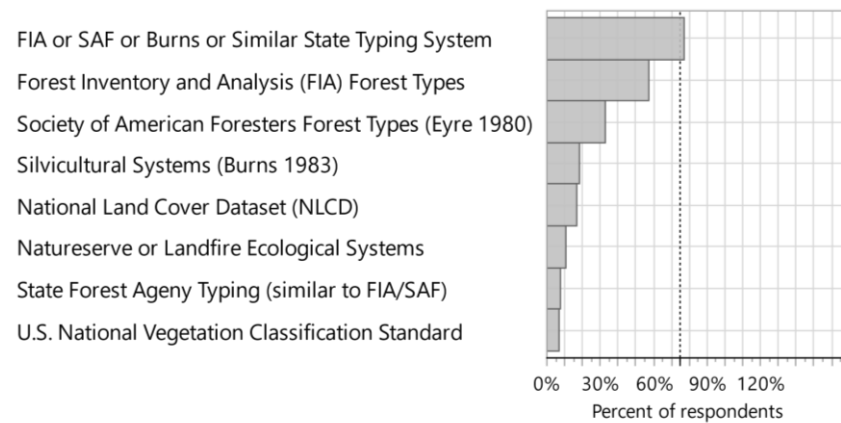


Figure 5. Common forest classification/typing systems used by forest managers. Dotted line represents 75% of survey respondents.

3.1.7. Landscape-Scale Variables for Which Forest Managers Would Like Information from Wildlife Scientists

We listed 17 a priori landscape-scale variables and asked forest managers to select those for which they would like to receive information from wildlife scientists. Six of these, all related to summarizing forest area by type or size/age class, were selected by between 45% to 79% of respondents (Figure 6). Two variables that provided stand-level summaries were selected by between 32% and 36% of respondents. Four variables related to fragmentation metrics were selected by between 18% and 28% of respondents, and all other variables were selected by less than 10% of respondents (Figure 6).

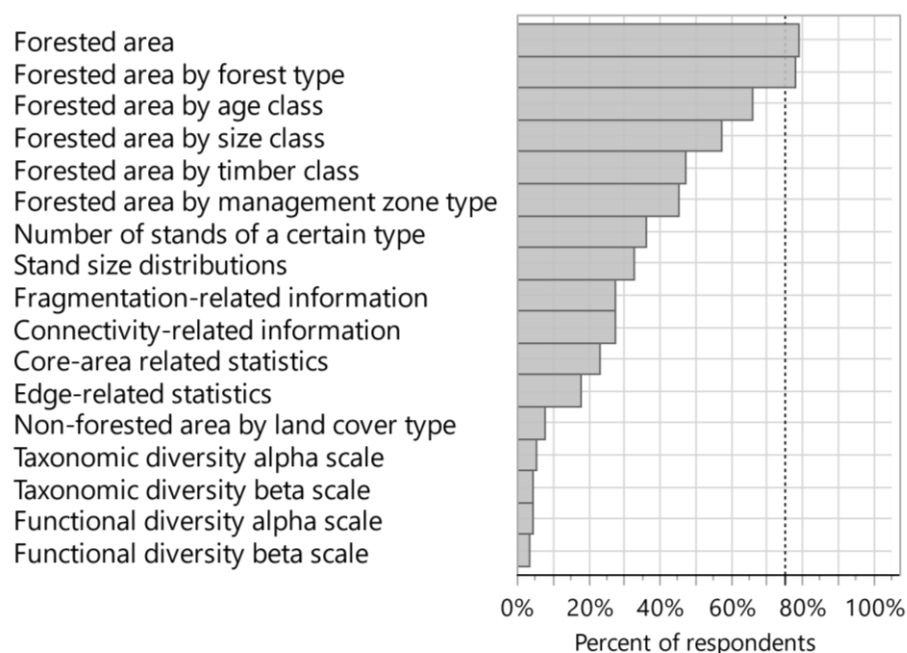


Figure 6. Landscape-scale variables for which forest managers would like information from wildlife scientists. Dotted line represents 75% of survey respondents.

3.2. Additional Information from Open-Ended Question Responses

Below, we provide specific excerpts from survey respondents that represent four recurring themes in text responses to open-ended questions.

3.2.1. Collect Data Using Forestry-Relevant Metrics

A very common theme in text responses was that information from wildlife scientists would be most useful if it was based on metrics that are used operationally in forest management. Here are five examples in the words of forest managers: (1) "Objective forest habitat attributes (basal area, trees/acre, diameter distributions, midstory, understory, groundcover)... are what is needed most... for wildlife species... but often either lacking or is vague in the literature"; (2) "Attributes MUST be described in metrics that operative field foresters use, such as Basal Area by species, diameter distributions, basal area by size class, etc. Using things like "canopy openness" or other obscure metrics that may be interesting to wildlife scientists aren't relatable to field metrics used by foresters in management"; (3) "Basal area, % stocking, tree species importance/relevance, age class distribution, show a basic understanding of silvics"; (4) "the more you can relate to us in terms of typical forest measurement data (basal area, crown closure, diameter, height, etc.) the easier it will be to implement management"; (5) "How changes in stocking affect various bird species. Rules of thumb for managing toward ideal stocking levels".

3.2.2. Collect Data for Forestry-Relevant Spatial Units

Another common theme in text responses was the need for wildlife scientists to provide information using the same hierarchy of spatial units as forest managers. Here are two representative examples: (1) “Being able to easily integrate management recommendations with operations at the stand and/or management zone/compartment scale is key to achieving desired habitat conditions.”; (2) “Wildlife species richness and species abundance at the stand, whole forest, and landscape level. Wildlife habitat type, quantity, and quality at the stand, whole forest, and landscape level”.

3.2.3. Summarize Important Within-Stand Habitat Elements for Different Species

Many agencies, and some forest certification schemes, have stand-level retention guidelines that specify which within-stand features should be protected or enhanced during forestry operations [97,98]. Many forest managers expressed an interest in summarized information on within-stand attributes that might be retained or enhanced for wildlife. Here are four representative text passages on this topic: (1) “Wildlife species associated with the presence/absence of specific habitat structural features/habitat components”; (2) “A summary document listing wildlife species and the most relevant stand elements for each species would be helpful”; (3) “Critically important habitat elements that can be identified at the stand level and handled appropriately, e.g., removed, enhanced, protected, etc.”; (4) “specific forest characteristics (coarse woody debris, snags, etc.) needed for specific species”.

3.2.4. Evaluate the Effects of Management on Species at Forestry-Relevant Temporal Scales

Understanding the process of vegetation succession is central to forest management. In most cases, forest succession and development take place over many years to decades. Key aspects of forest planning (e.g., rotation length) occur over even longer time periods. Many forest managers wanted more information from wildlife scientists about bird response to management or natural disturbances across the full temporal gradient of succession. Here are three representative text passages on this topic: (1) “Response time of wildlife to management activities”; (2) “time series that show the longevity of a treatment”; (3) “Outcome information that is tied to long-term research that helps foresters formulate wildlife friendly harvest practices”.

3.3. Identification of Review Papers That Provide Relevant Information on Forest Composition And/or Structure at Stand or Within-Stand Scales to Forest Managers

We identified 247 review papers from the 1173 that were evaluated (Figure 1) that provided information that forest managers wanted from wildlife biologists on bird species-forest composition relationships ($n = 133$) and/or bird species-forest structure relationships ($n = 228$). Citations for each of these papers are listed in Supplementary S5 (composition) and Supplementary S6 (structure). We provide brief summaries of some of the characteristics of these papers below and discuss our overall assessment of this evidence base, identifying important gaps and potential areas for future work, in the Discussion.

3.3.1. Many References Meeting Forest Manager Needs Were in the Gray Literature

Of the 247 references that we identified as providing potentially actionable information for forest managers on bird relationships with forest composition and structure, only 52 (21%) were published as journal articles (Figure 7). The remaining 195 (79%) were from gray literature that would be less likely to be discovered via searches of academic search engines. The three most common gray literature reference types were: reports published by non-federal, non-state institutions ($n = 71$, 28.7% of all references), conference papers ($n = 53$, 21.5%), and government documents (51, 20.7%).

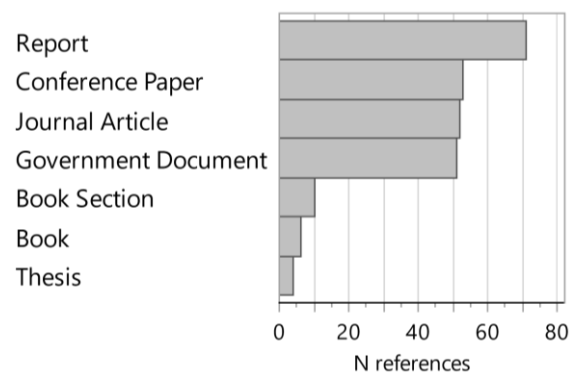


Figure 7. Reference types for papers that were selected for inclusion in Supplementary S5 and/or Supplementary S6.

Institution-published reports varied tremendously in depth, rigor, and reliance on published literature or expert opinion (Figure 8). We subdivided institutional reports into five subcategories reflecting their origins, four of which provided >5 publications that were included in Supplementary S5 and/or Supplementary S6: (1) Publications stemming from the North American Bird Conservation Initiative (NABCI) [99]; primarily Partners in Flight [100] and regional Habitat Joint Ventures [101] ($n = 27$, or 38% of all institutional reports); (2) publications by conservation-oriented non-government organizations (NGO) ($n = 19$, 26.8%); (3) publications from technical working groups comprised of partners from multiple NGO and academic institutions ($n = 17$, 23.9%); and (4) publications of cooperative forestry extension programs ($n = 6$, 8.5%).

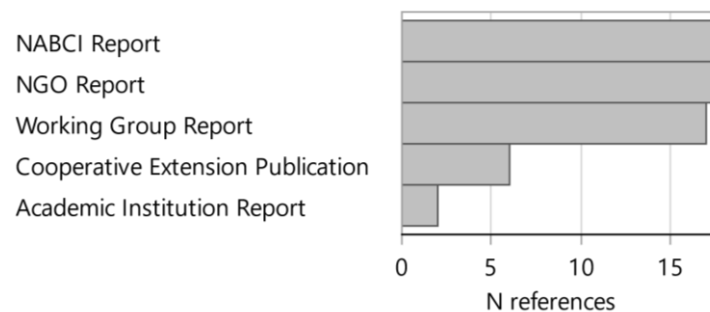


Figure 8. Types of gray literature reports selected for inclusion in Supplementary S5 and/or Supplementary S6.

We subdivided government agency reports into four different federal natural resource management agencies and a combined state agency report group (Figure 9). A large majority of these reports ($n = 41$, or 80% of all government reports) were published by the US Forest Service or the US Fish and Wildlife Service. The US Forest Service reports ($n = 25$, 49%) typically had a strong silvicultural research focus, whereas the US Fish and Wildlife Service reports ($n = 16$, 31.4%) were often related to habitat suitability indices that were prepared for numerous species in the early 1980s as part of the agency's habitat evaluation procedures [102–104].

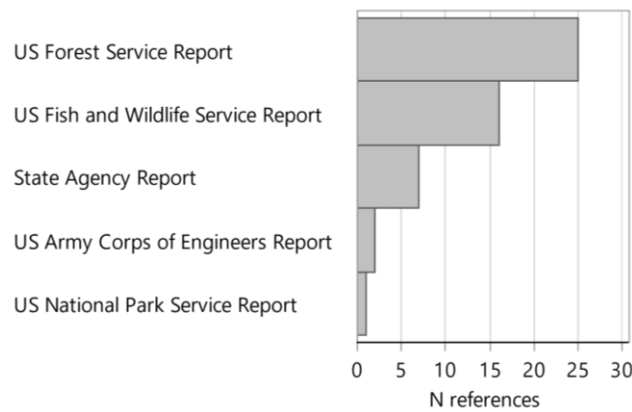


Figure 9. The 5 different agencies that produced documents grouped under the “government document” reference type.

Review papers with relevant information for forest managers were published in 30 different journals; however, the seven journals with >1 review paper that we assigned to Supplementary S5 or Supplementary S6 comprised 55.7% ($n = 29$) of all journal articles (Figure 10).

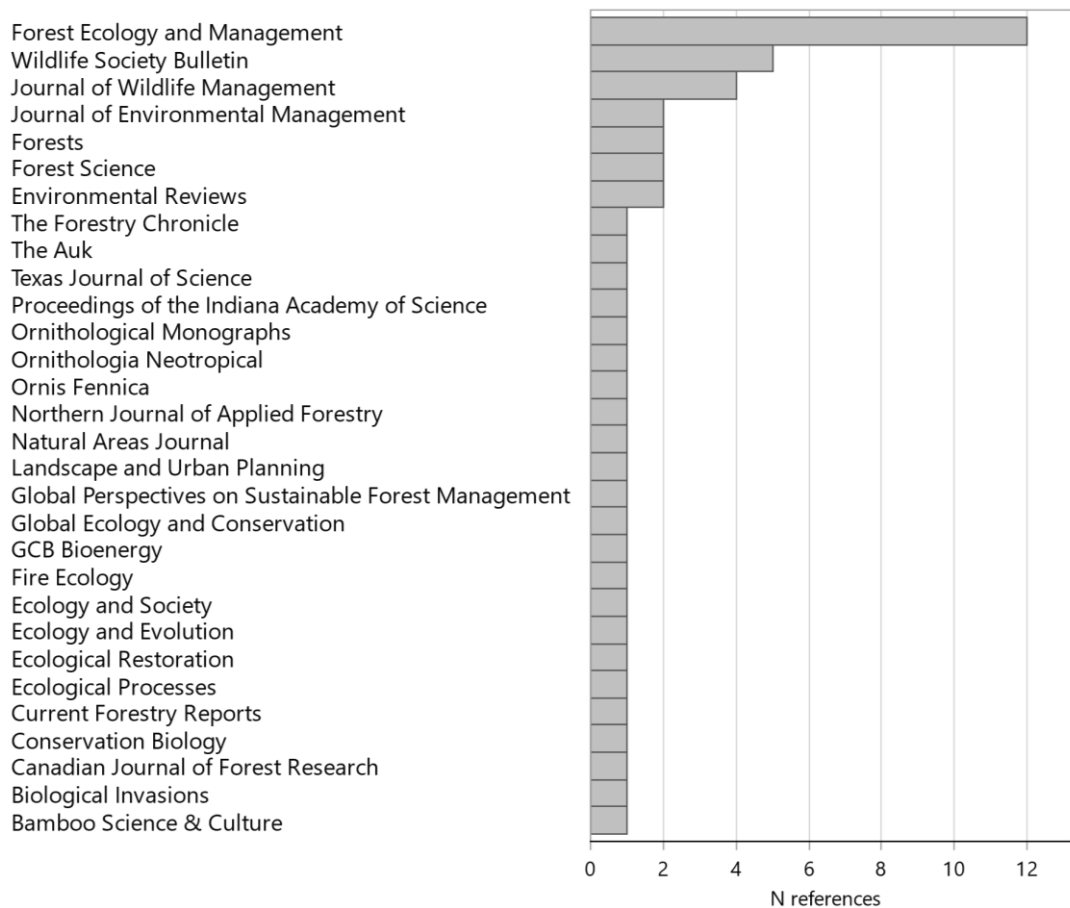


Figure 10. Journals with papers that were selected for inclusion in Supplementary S5 and/or Supplementary S6.

3.3.2. Temporal Changes in Document Types

Many different types of agencies and institutions have published information that may contain actionable information for forest management in the eastern United States. While much of this information has been published as gray literature, the exact sources of

this information have changed over time (Figure 11). For example, regional conferences on forest wildlife habitat relationships that were organized by the US Forest Service in the late 1970s and early 1980s provided many of the first summaries of forest bird–vegetation relationships for many of the forest types in the eastern US [23–27,35]. The US Fish and Wildlife Service published habitat suitability models for several forest bird species across the 1980s [102,105]. Review papers on forest bird–vegetation relationships were uncommon in peer-reviewed journals prior to the late 1990s. The 2000s saw a major increase in the number of review papers addressing forest bird–vegetation relationships originating from Partners in Flight, Habitat Joint Ventures, and NGOs. Similarly, each of the technical working group publications in Supplementary S5 and Supplementary S6 were published between 2010 and 2014. Technical reports from the US Forest Service and Cooperative Forestry Extensions, providing the strongest link with forest management of each of these document types, have been produced consistently, in small numbers, across this entire time series.

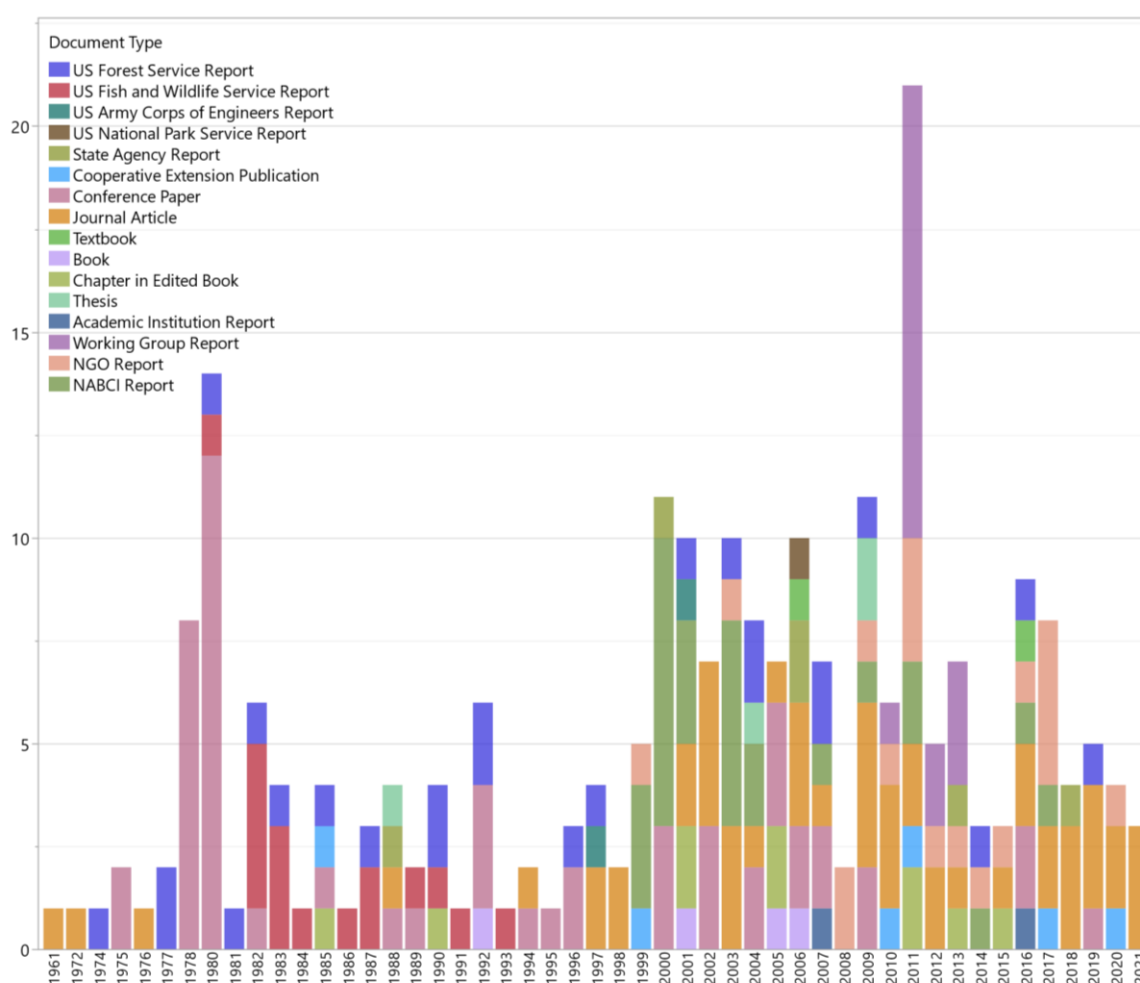


Figure 11. Temporal patterns in document types selected for inclusion in Supplementary S5 and/or Supplementary S6.

4. Discussion

4.1. Main Insights from Our Survey of Forest Manager Information Needs from Wildlife Scientists

Several important insights emerged from our surveys regarding ways in which wildlife research can be translated into actionable guidelines for forest managers. For example, forest managers want descriptions of wildlife species–vegetation relationships using the operational metrics of forest management (forest type, tree species composition, basal area, tree diameter, tree density, stocking rates, site index, etc.) summarized at the operational

spatial units of forest management (stands, compartments, and forests). In addition, managers would like more information on within-stand habitat attributes that are important for different species that can be protected, avoided, or enhanced (and integrated into stand retention guidelines). Finally, managers would like wildlife scientists to incorporate longer timespans into their evaluation of forest management impacts; showing a better understanding of how forest conditions, and habitat conditions for wildlife, change during succession over temporal extents that are longer than the typical wildlife research study. While we have listed review papers that specifically address bird species relationships with forest composition and structure in Supplementary S5 and S6, we provide specific examples below of reviews that did a particularly good job of summarizing information using operational frameworks and metrics of forest management. This is by no means, a comprehensive evaluation. However, we think that ornithologists and wildlife scientists will benefit from taking inspiration from these studies.

4.2. Examples of Review Papers That Meet the Key Information Needs of Forest Managers

4.2.1. Papers That Summarize Bird Species-Vegetation Relationships Using Operational Metrics Related to Forest Composition

Survey responses from forest managers were unambiguous about the importance of information on forest type (using classification schemes that rely on dominant tree species) and tree species composition (Figures 3 and 4). We identified 133 review papers that provide information on bird species relationships with specific forest types or tree species (Supplementary S5). These reviews, and the primary studies they are based on, show clear evidence for differences in occurrence, abundance, and community composition among forest types for many bird species (see Figure 12 for an example). There is also considerable evidence for strong relationships between different bird species and specific tree species, often related to nest site selection [106] or foraging habitat use [107,108]. This evidence contrasts with several influential studies from early in the development of theories of habitat selection that emphasized the importance of vegetation structure over composition [32,109]. Forest structure very clearly affects avian habitat selection; however, strong associations between different bird species and specific forest types [107] or tree species [110] are also common [111,112] (Figure 12, Supplementary S7 and S8). Given the importance of forest type and tree species composition to forest management, and the operational reality that forest composition and structure are always managed together, we see little value in dichotomous claims about the relative importance of forest composition versus forest structure, as both are important; both are manipulated by forest managers; both are affected by natural disturbances; both affect the distribution, abundance, and reproductive performance of wildlife; and both affect the overall functional resilience of ecosystems to future stressors and disturbances [113].

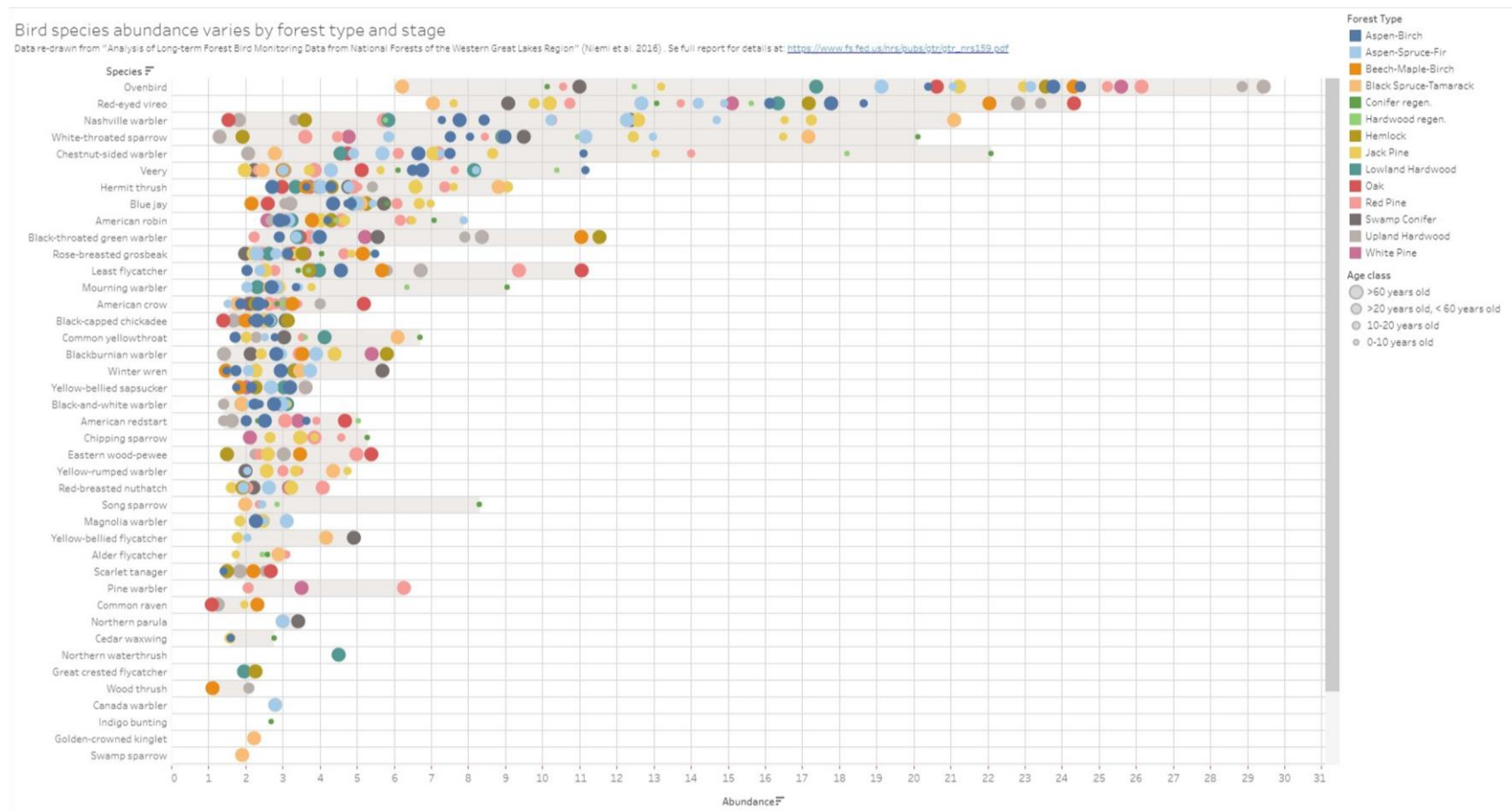


Figure 12. Variation in bird abundances by forest type/stage combinations as reported by Niemi et al. (2016) [114]. Dot colors represent forest type (see legend). Dot size represents stand age (see Legend). Horizontal lines that connect dots for each species represent the full range of abundances that were observed for each species across all forest type/stage combinations. An interactive version of this graph is available at: <https://public.tableau.com/app/profile/casey.lott/viz/ForestbirdhabitatassociationsinGreatLakesNationalForests/Sheet1> (accessed on 6 February 2021), https://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs159.pdf (accessed on 6 February 2021).

The importance of forest type and tree species composition to birds should be kept in mind whenever bird–vegetation relationships are studied. It is particularly important for ornithologists and ecologists to study and evaluate the effects of forest composition at the same thematic resolution as forest managers (e.g., forest types based on dominant/subdominant tree species) as 77% of our survey respondents reported the use of dominant tree species-based classification schemes (Figure 5). Management recommendations that have been proposed based on analyses of landcover datasets with more coarse thematic resolution (e.g., the NLCD categories of deciduous, evergreen, and mixed forest types) may neglect important differences in bird–vegetation relationships within the same broad categories. For example, bird species abundance and community structure may differ significantly between oak-dominated and maple-dominated stands within the same geographic region (both of which would be classified as the “deciduous” map category of the NLCD) [115]. Similarly, bird communities often differ significantly among coniferous forest types (e.g., red pine versus hemlock, shade-intolerant versus shade-tolerant species) [114]. In these cases, models that lump oak and maple forests into a deciduous forest category, or pine and hemlock forests into an evergreen forest category, are likely to suffer from extensive errors of commission (Figure 12). Similarly, silvicultural systems, and options for managing wildlife habitat within these, vary considerably among forest types within these coarse map categories. Consequently, management recommendations for “deciduous forest birds” are unlikely to have enough specificity to be acted upon by forest managers [116,117]. Currently, many bird species distribution models are based on the NLCD, as there are few spatially extensive remote sensing datasets that have mapped forest type over large areas at finer thematic resolution; but see Picotte et al. [118]. However, many forest management agencies plan for landscape-level management using stand maps for the forests within their management authority where each stand is classified to a forest type and stage. Ornithological studies that stratify sampling at this thematic resolution are likely to be more relevant, and more predictive, than studies over larger areas that rely on more coarse forest classification systems.

4.2.2. Papers That Summarize Bird Species–Vegetation Relationships Using Operational Metrics Related to Forest Structure at the Scale of Forest Stands

Forest managers prioritize information on forest structure at the stand scale that is collected and summarized using operational planning metrics of foresters, like basal area, tree density, tree diameter distributions, and stocking (Section 3.2.1). As one forester commented, studies that “account for site indices, seral stages, structural classes, and forest type all together are more useful than those individual stand-alone characteristics.” This perspective is perhaps best exemplified by the use of Gingrich stocking charts, which have been prepared for many forest types and silvicultural systems of eastern North America [119–122]. Stocking charts present information on three different stand attributes that relate to forest structure: tree density (trees/acre or trees/hectare), basal area (sq. ft/acres or m²/hectare), and mean tree diameter (usually quadratic mean in inches or centimeters). The intersection of these three measurements is then viewed relative to zones of growing space occupancy and stocking levels, specific to tree species, forest types, or silvicultural systems. Stands can then be classified as to whether or not they are understocked (e.g., not all growing space is being used), fully stocked (trees are growing well and all growing space is occupied), or overstocked (growth is slow due to competition of limited growing space). Stocking charts can then be used to make many different stand-specific decisions about intermediate treatments (e.g., thinning or crop tree release) or residual densities for regeneration harvests. The presentation of bird occurrence and/or abundance data on regional stocking charts could provide structural benchmarks directly relevant to, and easily manipulated by, forest managers (Figure 13), with opportunities for translation to similar tools in other regions, such as density management diagrams [123].

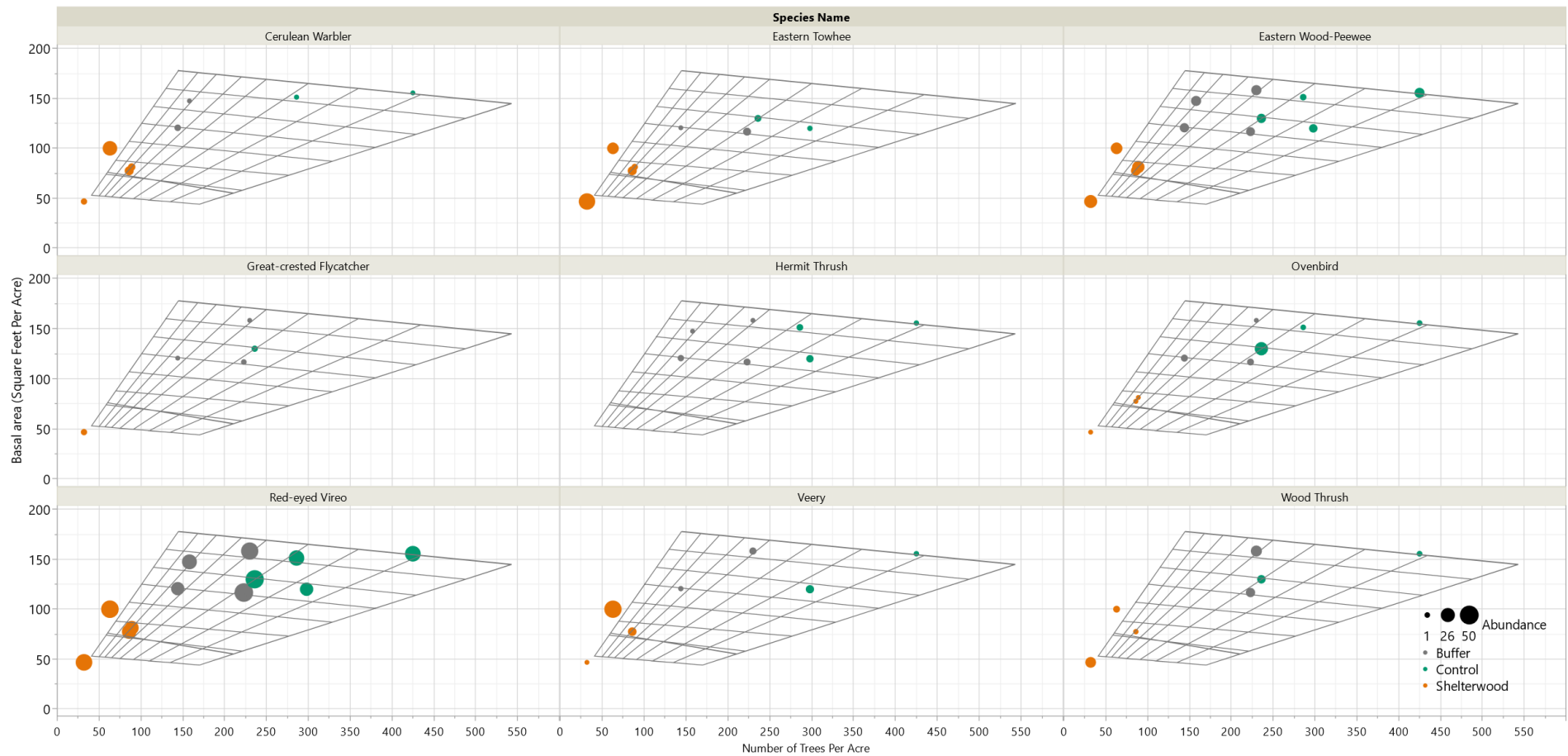


Figure 13. Density (birds/100 acres) of 9 common bird species in Northern Oak forests of western Pennsylvania (Stoleson, unpublished data) plotted, as dots, on a Gingrich stocking chart for Northern Red Oaks [122]. Uncut control stands (see inset figure legend) were typical of forests in the region with 70–100% stocking and much of the basal area in small diameter trees. Shelterwood stands (orange dots) had reduced basal areas and a greater proportion of the basal area in larger diameter trees.

4.2.3. Bird Habitat Models That Integrate Information on Forest Composition and Structure

One example of bird habitat models that incorporate forestry-relevant variables related to both forest composition and structure are the species habitat suitability models developed by scientists at the USFS Northern Research Station with their partners [124–126]. In many cases, these models are based on plot-based research into species–vegetation associations using variables that are recorded during several different types of stand inventories. Consequently, they are often directly linked to forest classification schemes and operational metrics of forest management. These are some of the few bird habitat models that incorporate information on forest type and developmental stages at same level of thematic resolution that is used in forestry (e.g., Forest Inventory and Analysis or Society of American Foresters Forest Types) [126]. Several of these habitat suitability models include indices specific to within stand features (e.g., snag densities) or plot-based vegetation measurements (e.g., small stem densities) based on data collected from empirical studies. This approach to habitat suitability modeling do an excellent job of meeting USFS requirements under NEPA, the NFMA, and the ESA, which require evaluation of species-specific information at high spatial and thematic resolutions over large spatial and temporal extents [127–129]. In contrast to many species distribution models that have been developed in the past decade, few of which have been independently evaluated with design-based accuracy assessment, habitat suitability models from the USFS Northern Research Station have been extensively validated; showing strong links between suitability indices and field-estimated reproductive performance [130,131]. One of the reasons for the strong performance of these models is the methodological approach of first defining key life history requisites for different species and then representing these explicitly as specific components of overall habitat suitability indices (e.g., forest type/stage associations, snag densities, distance to edge, distance to water, or landscape-scale forest cover) [102,105,124].

4.2.4. Papers That Summarize Important Within-Stand Habitat Elements for Wildlife

Most states in the US have their own stand-alone best management practices guidelines [132]. While these are often focused primarily on protecting soil and water quality, they also include recommendations for retention and protection of within-stand features that affect different wildlife species [97,133]. The degree to which guidance documents relied on evidence from syntheses of primary studies varied considerably among states and regions [9]. Some of the best examples of evidence-based recommendations for retention of within-stand features as wildlife habitat came from the Pacific Northwest, as these included extensive reviews of primary literature, standard sampling protocols to document existing conditions for both standing dead wood and logs, and decision support systems for evaluating stand management impacts on multiple wildlife species [134–140]. The state of New Hampshire has provided an example of practical stand retention guidelines that are well informed by evidence synthesis with recommendations expressed in metrics directly relevant to forestry operations [141,142]. We identified 228 review papers that provide information on bird species–vegetation relationships using stand attributes used by foresters (e.g., basal area, tree density) or relative to within-stand habitat elements (e.g., cavities, large trees, etc.) (Supplementary S6).

Many state harvest and stand retention guidelines are periodically updated. Recently, independent assessments have been completed of specific guidelines associated with live and deadwood retention in the context of bioenergy feedstock harvests at regional and international scales [9,143–147]. Wildlife scientists could provide a useful service to forest managers, and improve the scientific basis for forestry BMPs, particularly stand retention guidelines, with reports or publications that synthesize within-stand habitat elements of critical importance to wildlife species. Several excellent publications have been prepared that summarize cavity-nesting bird habitat needs in the forests of the eastern US, some of which provide explicit snag management recommendations [148–155]. While this information has been integrated into some best management practice guidelines [97,141,142],

many state harvest management and/or stand retention guidelines could be updated to better incorporate this important within-stand habitat need into operational guidance documents [149,152–155].

4.2.5. Papers That Summarize Bird Species-Vegetation Relationships at Forestry-Relevant Spatial Units

Forest management prescriptions are often applied to stands in order to meet the management objectives of land owners or agencies for larger areas (e.g., an entire forest's administrative boundary, management units or compartments within a forest, or management zones within compartments) [2,156]. Forest managers indicated that measurements of forest attributes would be most actionable if they could be used to guide stand-level prescriptions and multi-stand management decisions at the operational scales of compartments (or management zones), within the administrative scale of a forest. One possible barrier to the production of relevant information at these spatial units, is that key paradigms of wildlife science affect the way that wildlife scientists perceive the world, structure data collection, and summarize their results; resulting in the collection of information at other spatial scales or levels of organization. For example, the theory of multi-scale habitat selection states that conditions at multiple *spatial scales* affect wildlife species distribution, abundance, and reproductive performance [36,39]. Multi-scale studies often sample wildlife and vegetation attributes at points or plots (often referred to as "local-scale" variables [157,158]) and additional vegetation attribute data at spatial scales larger than the points or plots where wildlife data are collected. For example, focal patch/neighborhood studies may summarize forest cover at various radii surrounding a bird point count location [60]; proximity-based studies may report distances to specific features (e.g., water bodies, other similar vegetation patches) [159]; fragmentation-focused studies may report configuration metrics (edge density, patch size distributions) for even larger areas [69]. Collectively, data collected at scales beyond the original wildlife sampling plot are often referred to as "landscape-scale variables" [160–163]. In this case, the desire to understand how spatial scale affects wildlife results in collection of data that occurs either within stands in plots or across multiple stands in neighborhoods or landscapes of varying size. Additionally, organismal studies are often conducted within the paradigm of *multi-level* habitat selection, in which animals make a series of nested behavioral choices related to selection of: (1) geographic range, (2) seasonal home range, (3) specific components within a home range (e.g., a song perch or a foraging patch), and (4) specific resources, like food items [164]. Many studies in wildlife science reference one or both of these frameworks, and the two may often be conflated with each other [62].

While these conceptual and methodological frameworks are highly informative to the study of habitat selection, they are not particularly well aligned with the operational scales of forest management. For example, a forest planner may need to make decisions about how to allocate different types of management across a mosaic of stands within the administrative boundaries of their "forest," constrained by different types of zoning (e.g., wilderness, recreation areas, stream management zones, etc.) within compartments or management units [2,7]. These decisions are often informed by forest-wide inventories that summarize stand-scale attributes by forest type. For example, there may be targets for the percentage of area across a specific management authority's lands that contain different forest type/seral stage or timber class combinations (% of early successional areas that are regenerating as oak, % of stands of a particular forest type in the pole stage that may mature into saw timber in several decades, number of stands that meet a specific wildlife-habitat target like number of snags/acre). Plans to meet forest-wide objectives are then met by implementing prescriptions at stand scales. Evaluation of progress toward forest-wide objectives may then occur by rolling up outcomes across all stands [2]. Wildlife scientists may have more impact on forest management if they discuss how life history needs of organisms can be met via landscape scale planning based on stand mosaics and stand-level prescriptions. If wildlife scientists can better communicate with foresters using the operational scales, and metrics, of forest management, they will be more likely to find

the vast area of common ground that these disciplines (forestry and wildlife sciences) in fact share.

4.2.6. Papers That Evaluate the Effects of Management on Bird Species at Forestry-Relevant Temporal Scales

Bird species responses to natural disturbances and forest management occur at variable time lags from initial disturbance events. Some species may respond almost immediately to a clearcut, whereas others may peak in abundance a decade later. Other species respond to forest dynamics that occur over many decades (e.g., old-growth specialists). Some studies have shown that time since disturbance (e.g., years since harvest, years since fire) can be an outstanding predictor of species-occurrence or species-abundance relationships on their own [165,166]. Many outstanding review papers have described relationships between bird species occurrence, or species turnover, or community composition, in relation to the process of vegetation succession [167–173]. When evaluating the impacts of management, wildlife scientists must remain cognizant that long-term dynamics of forest development will result in different observable “effects of management” when studies are conducted at different points within a chronosequence.

Only a small fraction of primary studies that evaluate the effects of forest management on wildlife are longitudinal, with data collected at the same site(s) over a long time series [174,175]. These studies often provide valuable insights for forest managers. Many studies of forest bird-vegetation relationships use short-duration space-for-time substitution designs, which provide less reliable inference on temporal processes than time series data [176–178]. In many cases, conclusions about management impacts that are drawn from studies completed only two-three years after a management event, should be expected to change considerably during the following decades of succession. Consequently, we encourage wildlife scientists to: (1) evaluate the effects of vegetation management at temporal extents long enough to document wildlife species response across entire successional sequences, and (2) evaluate the effects of vegetation management across spatial extents broad enough to illustrate variability in the age of stands relative to major disturbances. Describing the effects of forest management should, by necessity, involve description of changes in forest landscapes at spatial and temporal scales to which wildlife populations respond [179]. Similarly, it is often difficult to place existing forest conditions in appropriate context without understanding the legacies of landscape change that have occurred over even longer time frames (e.g., New England over the past 400 years) [180].

While long-term field studies of bird response to succession and forest management are uncommon, dynamic forest landscape simulation models have been developed to compare forest vegetation response to management alternatives and natural disturbance over large spatial scales (e.g., an entire national forest, a large ecoregion) and temporal extents (decades to centuries) [181–183]. Habitat suitability models developed to pair with outputs from the forest landscape simulation model, LANDIS [184,185], have been used to predict changes in wildlife habitat quantity and quality in response to forest management, natural disturbances, and climate change at fine spatial resolutions (e.g., stands) and broad spatial (whole forest) and temporal extents (multiple rotations spanning more than a century) [128,186–189]. Several of these are particularly notable in that wildlife models have been built based on relationships between wildlife occurrence, abundance, or habitat selection and vegetation metrics with high relevance to forest management (e.g., forest types, stand development stages, vegetation structural attributes, and within-stand habitat elements) [124,126]. We encourage wildlife scientists to learn more about these specific applications, which have direct applicability to forest planning that integrates information on many wildlife species and multiple forest management objectives [127,129].

5. Conclusions

5.1. Learning from Past Research on Wildlife–Habitat Relationships

5.1.1. Wildlife–Habitat Relationships Have Extensive Documentation in Several Regions

Many of the original advances related to the study of wildlife habitat relationships in the United States emerged after the environmental laws of the late 1960s and early 1970s forced natural resource agency scientists to evaluate the effects of alternative management actions on species [6,30,102–104,190,191]. For forest birds, this translated into a number of publications that described bird species habitat relationships relative to specific forest types, developmental stages, and the silvicultural systems that are applied to these [107,192–208]. Two major regional efforts synthesized much of this information in book volumes that still represent the gold standard for the compilation of forestry-relevant information on forest wildlife habitat and management options. The book “New England Wildlife: Habitat, Natural History, and Distribution” [41] provided species accounts for 338 species of amphibians, reptiles, birds, and mammals in New England that describe stand-specific habitat features required by each species; including matrices that describe seasonal patterns of species occurrence by silvicultural system/forest type combinations. Two follow-up publications to this foundational reference provided technical guidance to both forest managers [209] and landowners [210] on how to manage forests, within appropriate silvicultural systems, to meet the specific habitat needs of this regional species pool. Similarly, the book “Wildlife Habitat Relationships of Oregon and Washington” compiled information on wildlife habitat relationships for more than 500 breeding species, across the same range of taxonomic groups, in the form of linked wildlife–habitat matrices; describing successional dynamics and structural characteristics of different regional forest types [138]; and providing exhaustive reviews on management options for within-stand structural features [134,137].

5.1.2. Habitat Suitability Models Link Forest Characteristics to Habitat Quality and Fitness More Directly Than Species Distribution Models

Species-specific habitat suitability models, first developed by the US Fish and Wildlife Service [102,211,212] and then refined by the US Forest Service [105], have been developed across a number of applications to address how well forestry-relevant vegetation characteristics meet the life history requisites of forest wildlife; producing maps that link habitat quality with fitness [124,130,131,213,214]. Advances in the development of dynamic forest landscape simulation models allows for the simulation of changes in habitat suitability, and wildlife population dynamics, over time, in response to different forest management alternatives, at the fine spatial resolution and broad temporal extents preferred by forest planners [127–129]. Bird habitat models applied to simulation outputs from dynamic forest landscape change models provide the critical ecological link between bird habitat use and succession and the ability to track the effects of forest management on wildlife at multiple temporal increments across broad temporal extents. This provides opportunities to understand forest bird population dynamics that are beyond the reach of most static, statistical species distribution models based on remote sensing data layers and species occurrence or abundance data [72,215]. When habitat suitability models are tied to the type of forestry-relevant metrics identified by our survey respondents (e.g., forest type, basal area, trees per acre), predictions can be made as to how different silvicultural prescriptions will affect wildlife species. Many of the statistical species distribution models that have been published in the past two decades have been built using explanatory variables that do not relate directly to forest composition or structure. These models provide little value to predicting the effects of forest management on wildlife. They also tend to under-emphasize the critical roles of succession and habitat management on shaping forest-dependent species distributions.

5.1.3. The Peer-Reviewed Literature Does Not, on Its Own, Comprise the Best Available Science on Forest Bird–Vegetation Relationships

As we note in our results, many of the publications that present highly relevant information on wildlife habitat relationships for forest managers are in the gray literature. Fortunately, much of this information is freely available online. The US Forest Service maintains an online publications database, called Treesearch, that archives >56,000 publications that were either published as Forest Service technical reports or journal articles with Forest Service coauthors. Many of the publications listed in Supplementary S5 and S6 can be located via this portal [216]. Similarly, full-text, online versions of many of the gray literature references reported herein can be located by searching Google Scholar for their title. However, many of these documents are unlikely to be found during keyword searches using Google Scholar. This apparent contradiction is due to Google's proprietary relevance ranking algorithm that appears to be highly influenced by citation counts, which leads to journal articles ranking higher than grey literature, regardless of their topical relevance [217]. As many of the grey literature references cited herein have not been cited widely, they tend to end up with low relevance values in Google searches. For some topics, this means that highly relevant grey literature may not be identified within the first several hundred results of a Google Search. Additionally, many of the major academic search engine platforms do not index grey literature. Consequently, exhaustive searches of these platforms are unlikely to turn up many of these references. Articles that search only academic databases, and do not access the extensive grey literature on forest wildlife habitat relationships and forest management are likely to miss considerable amounts of relevant material. One of our motivations for publishing this review is to connect both forest managers and wildlife scientists with this highly relevant gray literature, via the lists in Supplementary S5 and S6, and our in-text citations, which may be otherwise difficult to find.

5.1.4. Literature Search Strategies Focused on Wildlife–Habitat Relationships May Miss Articles on Management Systems That Provide Important Context to Wildlife Studies

The search string for our systematic map of primary literature [83] required references to include information on forest vegetation characteristics and birds. By linking these two topics with an AND operator, we automatically excluded review papers on forest dynamics and/or forest management that did not include any information on birds. However, these are probably some of the most important references for ornithologists and other wildlife scientists to read in order to develop a better understanding of the opportunities and constraints related to habitat management in different silvicultural systems, and to be able to better structure wildlife research to more directly inform management action. The depth of knowledge on forest and management dynamics that can be found in these references is usually far greater than forest habitat descriptions written by ornithologists or wildlife scientists with no forestry background [2,218,219].

6. Recommendations

6.1. Use This Review to Familiarize Yourself with Prior Literature on Wildlife–Habitat Relationships

We believe that ornithologists, wildlife scientists, ecologists, foresters, forest planners, and silviculturists could all benefit from more closely examining the subset of management-relevant references on forest bird–vegetation relationships documented herein (and listed in Supplementary S5 and S6). Specifically, we recommend that wildlife scientists working on eastern forest birds in the United States become familiar with USFS documents on forest types and silvicultural systems that are widely used by forest managers and less frequently cited by wildlife scientists [28,29,220,221]. Similarly, we recommend that wildlife scientists read review papers on the silvicultural methods that apply directly to their study system prior to designing field research projects that propose to evaluate the effects of management.

6.2. Wildlife Scientists and Forest Managers Should Try Harder to Learn More from Each Other

The disparity between the information that forest managers deem relevant and the information that is presented in publications from many wildlife scientists is problematic. We suggest that ornithologists specifically, and wildlife scientists in general, should more carefully consider the opinions of forest managers, as reflected in this publication, regarding the information they need to manage wildlife habitat. While this is by no means a new recommendation, it's still very true that managers and scientists need to interact with each other, and influence each other's work, way more frequently than they currently do [2,74,222]. As a first step, wildlife scientists and forest managers could spend more time together in the field during the breeding season/growing season. This would help wildlife scientists and forest managers develop a common understanding of the range of variability that occurs across study regions and operational landscapes [2]. Additionally, wildlife scientists, foresters, and forest planners could work to find additional avenues for face-to-face interactions. Spending time together at conferences or working group meetings will help both groups find pragmatic ways to integrate key habitat management considerations for birds into silvicultural practices [89]. In the end, the science–practice gap will only be bridged, and the co-production of actionable science will only occur, when wildlife scientists and natural resource managers take the time to develop common understandings that are both specific and operational [74,90,223].

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/f12080990/s1>, Supplementary S1: Complete text for the online survey instrument, Supplementary S2: Survey invitation letter to forest managers, Supplementary S3: All un-edited text responses to open-ended questions, Supplementary S4: Answers to survey questions not reported in the article's main text, Supplementary S5: List of review papers that report bird-vegetation relationships at the thematic resolution of forest type or tree species, Supplementary S6: List of review papers that report bird-vegetation relationships with forestry-relevant stand structural attributes or specific within-stand features. Supplementary S7: Interactive data visualization showing variation in bird species abundance by forest types/age classes, based on static Figure 12 in the main text, Supplementary S8: Interactive data visualization showing variation in bird species habitat use by forest tree species.

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Informed Consent Statement: Participants provided information anonymously and willingly in response to an online survey that transparently disclosed how information would be used in a publication (see Supplementary S1 and S3).

Data Availability Statement: The data presented in this study are available in Supplementary S1–S6.

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