Developing an alternative approach to wildlife management in the Duke Forest

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Executive Summary

Duke Forest is a multi-use institution with the stated goals of research and teaching, education and outreach, sustainable timber harvest, ecological conservation, and recreation. The overall mission of the Duke Forest regarding wildlife management is "the encouragement and maintenance of a diversity of wildlife species representative of the many animal communities native to the Piedmont of North Carolina." In its current iteration, the wildlife management plan lists many outdated objectives and practices no longer implemented by Forest staff. Wildlife management tends to be the byproduct of silvicultural prescriptions, taking steps to mitigate any damage to wildlife habitat during timber harvests, rather than managing for wildlife habitat.

Duke Forest staff tasked us with creating a plan that would manage for wildlife more meaningfully, taking specific actions to encourage and maintain native Piedmont biodiversity. To accomplish this task, we defined three objectives: (1) explore potential wildlife management approaches and work with Duke Forest to finalize a framework, (2) evaluate management implications and work with Duke Forest to determine feasible implementation strategies, and (3) consider monitoring needs and options, and how data might inform management.

To evaluate the efficacy of, and compare, a variety of wildlife management and monitoring alternatives, we conducted two multi-criteria decision analyses (MCDA). The first MCDA compared trade-offs among competing wildlife management alternatives. We identified alternatives via a survey of peer institutions, assessed the outcomes of these alternatives by conducting a systematic review of the identified alternatives and calculating an effect size for each, and engaged our clients to provide input regarding their preferred outcomes.

We identified management practices common among twenty-seven peer institutions across North America, and assessed the efficacy of each by conducting a systematic review of studies that analyzed the effect of a management practice on either individual species abundance or overall species richness. We located several existing meta-analyses that examined the effects of assorted management practices, but, where necessary, filled in research holes by returning to the results of our systematic review. We then compiled taxa-specific tables listing the effect of each management alternative included in our analysis as a function of individual species abundance and overall species richness.

The magnitude and direction of effects were inconsistent between taxa. We found that birds generally respond positively to manipulations involving fire and harvest practices, but negatively to deadwood manipulation. The outcome of management practices on mammals was, on the whole, insignificant. Reptiles showed positive response to harvest practices, but were insignificantly effected by other practices. Amphibians displayed a significant negative response to harvest practices. Other practices' outcomes were generally insignificant to amphibians, and the only positive outcome was seen with the application of high intensity fire.

Having assessed the outcome of each management alternative, we determined our client's preferred performance weights and outcomes. Duke Forest staff chose to weight richness higher than abundance, and preferred a 'do no harm' approach to managing wildlife, where relative satisfaction is directly proportional to the increase in biodiversity achieved. The final decision tables provide a 'score' that can be used to compare alternatives.

The finalized decision tables were compiled into a dynamic document, designed as a stand-alone tool that can be adapted to accommodate new information or shifting priorities. In addition, we provided recommendations to the Duke Forest using approaches to both wildlife management and community-based monitoring.

Because of Duke Forest's limited resources, we focused on the use of community-based monitoring, a form of citizen science, to address the final objective. To determine the applicability of such a program for monitoring wildlife in Duke Forest, we conducted interviews with eighteen professional citizen science practitioners across the country and conducted a systematic review to address data quality concerns raised consistently throughout those interviews.

The most frequently reported benefit of using citizen science was increased public engagement, while the most frequently reported challenge was the need for proper training. The most frequently used and most recommended method to promote data quality was to ensure a proper protocol was in place, followed by involving experts to the project. We asked Duke Forest to rank species priorities, data collection preferences, type of resources available, and overall monitoring objectives, and used these preferences to conduct a second MCDA comparing three citizen science alternatives: a single-day bio-blitz, an existing long term program, and a new long term program. Based on Forest staff's preferences and the available data, the use of an existing long term monitoring program received the highest score.

In managing for wildlife, we first recommend that Duke Forest promote biodiversity through habitat diversification at multiple scales. Duke Forest should identify and establish Piedmont-specific habitat thresholds for the entire forest while maintaining habitat evenness, via the Berger-Parker index, within individual divisions. Second, on non-harvestable land, we recommend establishing habitat zones that can be managed dynamically to promote habitat evenness. Third, Duke Forest is located in the greater Piedmont geophysical region, which has the highest amphibian biodiversity in the US, and should therefore prioritize amphibians where possible. The importance of this focus is underscored by the significant negative impacts of harvest practices on amphibians, demonstrating the sensitivity of this important taxa to a variety of management activities. Finally, monitoring, focused on richness especially, should be conducted before and after management activities.

For monitoring purposes, we recommend starting with a small and simple focus. Based on priorities given to us from the Forest staff, we recommend beginning with a program that focuses on herpetofauna. We also recommend using an existing long-term program to better tap into existing resources, such as protocol and program design. We stress the importance of matching project goals to volunteer interests if the Duke Forest wishes to establish a successful, on-going community-based monitoring program. Finally, the Forest should involve both scientific and community engagement experts to help instigate a pilot program specifically within the Duke Forest. In this small-scale trial, getting feedback from the volunteers regarding why they are participating, as well as any improvements that can be made to improve the project, is extremely important.

Contents

1. Introduction

The southeastern United States has remarkably high levels of wildlife diversity, resulting from the variety of habitats created by regional gradients in climate, topography, and geologic site conditions (Stein 2002). North Carolina in particular harbors exceptional concentrations of animal biodiversity, leading the US in amphibian richness (Stein 2002, Wear and Greis 2013). The majority of this diversity is located in the Piedmont geophysical region, supporting 528 native vertebrate species within twenty-two ecosystems (Wear and Greis 2013). However, this region is experiencing major shifts in land use, which will undoubtedly impact this incredible variety of life. Since the 1970s, US timber harvests have been concentrated in the country's southeastern states, a trend that the USDA Forest Service predicts will continue well into mid-century (USDA 2011). Beyond conversion to plantation, a substantial increase in urban development is expected over the next fifty years (Wear and Greis 2013). These trends will be focused even more intensely in the Piedmont, where 19% - 21% of forested area is expected to be lost by 2060 (Wear and Greis 2013).

Increasing rates of timber production present potential problems for preserving the region's extreme wildlife diversity. Several studies demonstrate that forest management practices can have detrimental effects on native vertebrate species by homogenizing habitats, reducing microhabitats, and introducing non-native species (Rosenvald and Lohmus 2008, Vuidot et al 2011, Chaudhary et al 2016). However, other evidence suggests that actively managed forests do not necessarily lead to a reduction in biodiversity (Gustafson et al 2009, Lafond et al 2015). Furthermore, existing research is often accused of favoring certain taxa, geographical regions, and ecosystems (Zuidema et al 1996, Rosenvald 2008). Given the conflicting evidence and potentially narrow scope of inference, synthesizing this research for use by forest managers is a challenge that remains unmet. As no conclusory body of evidence exists regarding the effects of common forestry practices on native species, no framework exists to guide forest managers in addressing the compound interests of a multi-use forest. Moreover, Kurtila et al (2001) suggest that we cannot assign best practices across all forests, due to the differing situations and requirements of each.

Duke Forest is interested in determining how wildlife management can best be balanced with competing forest uses, and presented us with the following objectives in developing a novel approach to wildlife management in the Duke Forest:

1. Explore potential wildlife management approaches and work with Duke Forest to finalize a framework.
2. Evaluate management implications and work with Duke Forest to determine feasible implementation strategies.
3. Consider monitoring needs and options and how data might inform management decisions.

We here seek to develop a more comprehensive understanding of the effects of forest management, and silviculture in particular, on wildlife. We also investigate how community-based monitoring programs may be implemented to supplement limited formal monitoring resources. Our aim is to create an adaptive framework that compares the impacts on wildlife diversity of competing forestry alternatives and to identify existing citizen science programs that are best suited to monitor their outcomes. This tool will prove invaluable in helping the Duke Forest achieve its mission in maximizing Piedmont biodiversity.

1.1 The Duke Forest

The Duke Forest, whose origins date back to the 1920s, was originally intended as both a working timber forest and an experimental laboratory for forestry research (Korstian and Maughan 1931). Its use has since expanded, and now serves as an outdoor laboratory for many environmental and biological sciences while still being actively managed for timber (DFMP 2015). The primary aim of the Duke Forest regarding wildlife management is the "encouragement and maintenance of a diversity of wildlife species representative of the many animal communities native to the Piedmont of North Carolina" (DFMP 2015). This is accomplished primarily through silvicultural prescriptions and timber management practices that seek to create a wide variety of habitat within the Forest's bounds. The current management plan, last updated in 2015, recommends three practices to better foster biodiversity and ensure the continued existence of resident species: increasing non-forested land coverage, continuing to harvest mature pines and promote the regeneration of younger pine stands, and promoting and protecting lowland hardwood communities (DFMP 2015).

Managing habitat in the Duke Forest is predominantly a process of managing stand size and open areas. In managing stands, the Forest is interested in ensuring that at least some stands are large enough to provide habitat for interior specialists, while also maintaining existing edge habitat. To wit, the Forest has indicated that stands less than one acre should be combined with other stands until a minimum area of one acre is met (DFMP 2015). Furthermore, expansive stands may have areas within cleared to create additional edge territory. Forest clearings have been identified as especially important for species native to the Southeastern United States (Menzel *et al.* 1999, Dickson 1983). The existing management plan therefore calls for periodic mowing to encourage both new herbaceous growth as well as colonization by arthropods (DFMP 2015). Clearings for powerline right-of-ways create natural corridors and enable the rise of early seral vegetation, a preferred habitat for many Duke Forest species (Litvaitis 2001, Anderson 1991). Finally, the Duke Forest has, in accordance with the North Carolina Wildlife Resource Commission (2002, 2009), established Riparian Management Zones around permanent and ephemeral water bodies to provide increased habitat and better facilitate movement of many native species through the landscape (DFMP 2015).

Wildlife management activities generally seek to increase habitat diversity at both the landscape and stand level, but this is mostly due to lacking comprehensive species lists and related population estimates (DFMP 2015). Directors of the Forest, presently lacking a habitat guide specific to the Piedmont of North Carolina, use Evans' (1974) description of Missouri forest habitat to guide decisions (DFMP 2015). As such, habitat has been managed towards coverage being comprised of 20% permanent open field, 40% mast-producing species, 10% old growth forest, and the remaining 30% a combination of maturing pine and mixed hardwood forest (Evans 1974). These habitat composition goals are used in conjunction with the Shannon diversity index to maximize potential habitat diversity within the confines of Duke Forest (Dickman 1968, DFMP 2015). The data used to compute this index appears to have come from a 1997 timber inventory and cover typing efforts from 2004 (DFMP 2015).

1.2 Measuring biodiversity[1]

We are also interested in examining the variety of biodiversity metrics that are best suited for integration within the Duke Forest Management Plan, an actively managed forest in the North Carolina

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[1] The following section, and subsequent sections relating to the measure of biodiversity, is adapted from Palmer-Dwore and Satin (2016), unpublished.

Piedmont. Because increased wildlife diversity is a stated goal of the Forest, we will not explore the ongoing debate of the importance of biodiversity and its implications for ecosystem stability and resilience (Holling 2001), but will rather limit our scope to an analysis of the efficacy of the more common biodiversity metrics for use in the Duke Forest.

Most measures of diversity fall into one of three categories. A species richness index, perhaps the most straightforward of these categories, quantifies the number of species present in a given sampling unit. The second category, species abundance models, are more concerned with the evenness of a given sampling unit, and are usually described via the model that best represents the abundance distribution. The final group consists of indices that are based on the proportional abundance of each species within a sampling unit, and are usually some synthesis of richness and evenness into a single value (Magurran 1988). A brief summary of the mechanics of each of these categories follows below.

1.2.1 Species richness indices

Species richness is a seemingly straightforward technique that can quickly become very complicated. Raw species richness *S* is dependent on a system staying static through space and time, and requires that each species in the system be enumerated and identified (Magurran 1988). Such thoroughness is often difficult, if not impossible to achieve in the real world, so ecologists must instead rely on sampling, which requires controlling for effort. Numerical species richness (Kempton 1979) normalizes species richness per number of individuals, while species density (Hurlbert 1971) relies on unit area. Both measures assume that richness will stay constant across both sampling area and sampling effort, but in most cases the number of species tends to increase with increasing sample size and sampling effort (Magurran 1988). To account for this, Hurlbert (1971) refined a technique, called rarefaction, that results in an unbiased assessment of the expected number of species in each sample if all samples were standardized. Unfortunately, rarefaction sacrifices much of the relative abundance data required for normalization, data that is often more useful in describing environmental sensitivity than richness itself.

1.2.2 Species abundances models

In an effort to quantify biodiversity in a way that better reflected actual community structure, ecologists began developing species abundance models, which describe mathematically the observation that, in most communities, species abundances are not distributed equally. Although abundance may be described via multiple distributions, ecologists tend to focus on four models in particular, here listed in order of favoring dominance to favoring evenness. The geometric series, which follows the niche-preemption hypothesis, describes a community wherein the most abundant species utilizes a proportion of a limiting resource, the second most abundant species utilizes the same proportion of what is left of that resource, and so on, until all species have been accounted for (Magurran 1988). Such models describe communities with very low evenness, and tend to be observed in harsh, species poor environments, or where a landscape is in the early stages of succession (Whittaker 1972). The log series, like the geometric series, often applies to unsaturated habitat where the community ecology is dominated by only a few limiting factors (Magurran 1981, 1988). However, whereas the geometric distribution describes species arrival at regular intervals, a log distribution would be predicted for environments where species arrival was random (Boswell and Patil 1971, May 1975).

A lognormal distribution is to be expected in large, mature communities that have been well-studied, although whether this is due to statistical theory or reflects actual ecological processes is open to debate (May 1975, Pielou 1975, Sugihara 1980). Nonetheless, the log series index, a constant derived from the sample dataset, is often used as an index of diversity (Taylor 1978). A final broadly applicable distribution results from the broken stick model, which is predicated on niche space being divided randomly and simultaneously among species within a community (MacArthur 1957). Like the geometric and log distributions, it is a single parameter model, although it results in a much more equitable division of resources (Magurran 1988). It should be noted that, of the above models, only the geometric and broken stick models are rooted in biological theory, and that the ecological assumptions of both of these models have been largely unproven or discredited (Magurran 1988). Moreover, constructing these models can be labor intensive, and do not immediately provide managers with an index by which to compare diversity temporally or spatially. A more useful distribution method which accounts for species distribution but requires no model fitting is the Q statistic, which measures the interquartile slope of a cumulative species abundance curve (Kempton and Taylor 1978). This measure has the advantage of providing a diversity index that is weighted towards neither abundant nor rare species.

1.2.3 Proportional abundance indices

Fitting species abundance models is a tedious affair, and the variety of communities sampled may have different distributions, making direct comparison difficult. To account for this, a number of proportional abundance indices have been proposed that take into account both species richness and evenness and are not reliant on the underlying shape of an abundance distribution (Peet 1974, Southwood 1978). These so called heterogeneity indices can be divided into information indices and dominance indices (Magurran 1988). Information indices, derived from information theory, are the most commonly applied indices, with the Shannon[2] index ranking at the top. The Shannon index is predicated on the assumption that individuals are sampled from an infinitely large sampling pool, and that each species present in the community is sampled (Pielou 1975). It is generally calculated as

$$H' = -\sum p_i \ln p_i$$

Where p_i is the proportion of individuals of a particular species. This index is well suited towards species rich systems, but increasingly large errors are introduced as species richness dwindles, or if any species are left out of the calculation (Peet 1974). The Shannon index is also useful in comparing the diversity among many communities, as the index itself tends to become normally distributed with repeated sampling (Taylor 1978, Magurran 1988). For instances where random sampling cannot be guaranteed, or where the community is being censused, the Brillioun index may be used (Pielou 1975). However, this index is uncommon due to its complex calculation and dependence on sample size (Magurran 1988).

The other group of heterogeneity indices is the family of dominance measures, which heavily favor evenness over richness. The most well-known dominance index is the Simpson index, which describes the probability that any two individuals drawn from an infinitely large sample will be from different species as

$$D = \sum p_i^2$$

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[2] The Shannon index was independently derived by both Shannon and Wiener, and is therefore sometimes referred to as the Shannon-Wiener index (Magurran 1988). An alternative naming convention, Shannon-Weaver, is incorrect (Krebs 1985). We will hereafter refer to it only as the Shannon index.

As *D* increases, diversity decreases, so Simpson's index is generally expressed as either 1-*D* or 1/*D.* The Simpson index is heavily biased towards abundant species and is not especially sensitive to species richness; in fact, in communities exceeding 10 species, it is often necessary to know the underlying species abundance distribution to interpret the result (May 1975, Magurran 1988). An even simpler dominance index, the Berger-Parker index, is defined as the number of individuals of the most abundant species in the sample divided by the total number of individuals for each sample. The inverse may then be taken so that an increase in the value depicts an increase in diversity. The Berger-Parker index is independent of species richness, but, like the Simpson index, views decreasing dominance (and thus, increasing evenness) as a proxy for diversity (Magurran 1988).

1.2.4 Non-species diversity measurements

Land managers are often interested in determining the diversity across an entire landscape, which requires assessing the diversity of habitats within the area of interest. In classifying habitat types, it is necessary to delineate the variety of structural diversity present in the landscape (MacArthur and MacArthur 1961, Elton 1966, Bunce and Shaw 1973). Components of structural diversity include somatic polymorphism, varying age classes, genotypic variation, and the variety of microsites present in the habitat (Harper 1977). Once the habitats have been specified, diversity is calculated through a simple habitat richness count or by using one of the above indices and replacing the proportional abundance of species with the proportion of habitat (Magurran 1988). The use of abundance in this case is not as straightforward as counting individuals of each species; it is often most useful to use biomass, percent cover, or frequency as a proxy (Hengeveld 1979).

1.3 Community-based monitoring

The concept of adaptive management coined by Holling (1978) includes the need to monitor management implementations to assess the effectiveness of the management strategies and then return to the planning phase when potential changes should be made. Community-based monitoring, often referred to as citizen science, has been used in many scientific fields for a long time, such astronomy and ornithology (Marshall and Fletcher, 2014; audubon.org). One of the first organized, large scale citizen science efforts was the Christmas bird count, which started in 1900 (http://www.audubon.org/history-christmas-bird-count). Since then, citizen science has become more common for use in the natural sciences. Specifically, citizen science has dramatically evolved as an effective tool in the mid 2000's when smartphone technology made such data collection techniques easily accessible to a larger population than ever before (Silvertown et al., 2015). In an adaptive style framework, there are many ways in which a citizen science approach could be adopted. Three overarching models of citizen science are defined by Bonney et al. (2009) as contributory, collaborative, and co-created. Contributory incorporates the least amount of citizen involvement, while co-created involves the most community time. In between lies collaborative, where citizens are collaborating with scientists but not aiding in management decisions. Community-based monitoring falls between contributory and collaborative, depending on exact project guidelines.

The community-based monitoring approach incorporates a greater necessity for scientists to understand underlying social constructs which affect the quality of such citizen derived data (Lewandowski et al., 2015). Due to the 'unprofessional' nature of citizen data, many scientists continue to question the reliability of such monitoring data; however as increasing numbers of published studies are both using citizen science data and investigating the quality of overall data, the accepted validity of citizen collected data is on the rise. Jordan et al. (2015) stated that including the greater community in adaptive management plans actually increases the resilience of the monitored area from large social and environmental disturbances. Given the extensive background and evolving uses of citizen science, there may be a potential application of such monitoring within the Duke Forest.

2. Conducting a multi-criteria decision analysis

2.1 Methods

In developing a novel wildlife management approach for the Duke Forest, and to ensure that we met their stated objectives, we employed a multi-criteria decision analysis (MCDA). MCDAs are useful tools for identifying and comparing the outcomes of alternative management options and determining which of those best satisfies management objectives (Maguire 2014). They rely on extensive stakeholder engagement to define the scope of objectives implicit in any management action, the relative satisfaction associated with the outcomes of each alternative, and the relative importance given to each measure of success (Maguire 2014). We collaborated closely with the staff of the Duke Forest to best capture their preferences at each step of the decision making process, but other potential stakeholders include Duke research faculty and Durham residents, who use the Forest for research and recreation, respectively.

While Duke Forest also specifies objectives pertaining to research and education, resource management, outreach, and recreation, we here concerned ourselves only with its "encouragement and maintenance of a diversity of wildlife species representative of the many animal communities native to the Piedmont of North Carolina." Our scope of management alternatives and ecological outcomes therefore explicitly pertains to promoting biodiversity in both abundance and richness. For the following analysis, we used the multi-attribute utility analysis variant MCDA, which weighs the perceived satisfaction of a range of outcomes across management alternatives (Maguire 2014).

2.2 Results

In collaboration with input from Duke Forest, we established an objectives hierarchy (Figure 1) that achieves the Forest's stated goal of promoting biodiversity through encouraging the component aspects of individual species abundance and overall species richness.

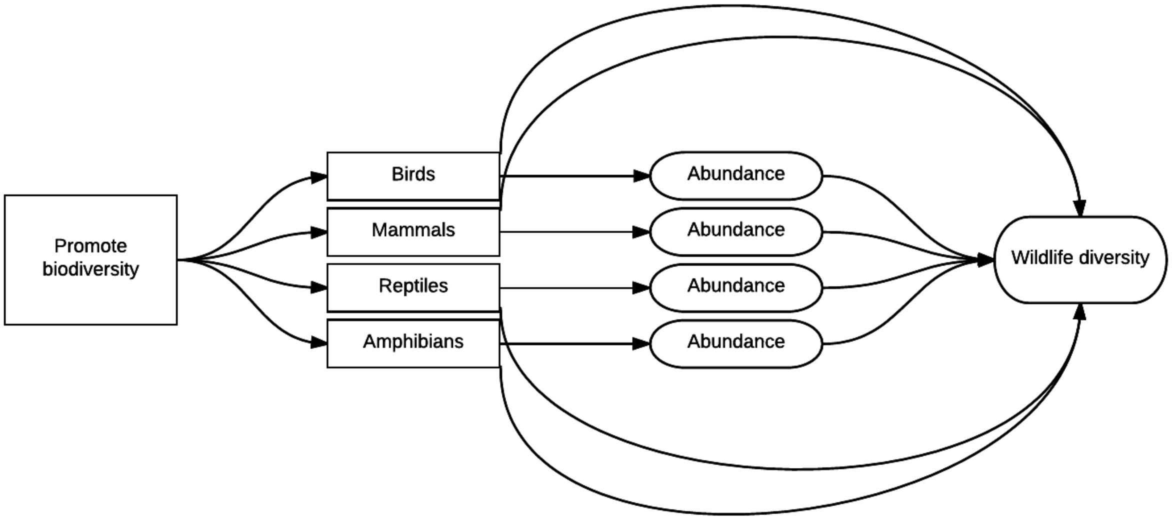

Figure 1. Duke Forest's wildlife management objectives and relevant indicators.

2.3 Discussion

This analysis was conducted solely in collaboration with staff of the Duke Forest, although other stakeholders, including Duke University faculty and the greater Durham community, should be consulted to determine their goals and preferences regarding wildlife. Engaging those who recreate in the forest may reveal a preference for more wildlife sightings, implicitly favoring abundance over richness, or may help identify charismatic species for targeted management. On the other hand, faculty conducting research in the Forest may share Forest's staff preference for increased diversity. Duke Forest staff should consider the preferences of these other interested parties before committing to a wildlife management alternative. Furthermore, competing usage goals may affect the feasibility of any of the investigated alternatives. For instance, portions of the Forest managed for timber may preclude the use of certain alternatives, while cultural heritage sites and streamside management zones may similarly restrict what Forest staff can do to promote biodiversity.

3. Identifying wildlife management alternatives

3.1 Methods

Our assessment began with an investigation of the variety of wildlife management techniques most commonly used in forests analogous to the Duke Forest, that is, working forests with a significant focus on research and education. Because management plans follow no set standards in terms of format or content, a formal systematic review was ill-suited to address our objectives. We instead pursued a meta-synthesis, an emerging qualitative investigatory technique gaining popularity in the nursing and health fields. While still in its infancy, meta-syntheses are attempts to make rigorous, broadly applicable interpretations from personal narratives and experiences (Jensen and Allen 2006). Meta-syntheses are specifically designed to accommodate phenomenological data, and within the environmental field, tend to investigate how people experience nature (Sandelowski et al, 1997, Barnett-Page and Thomas 2009). Because the specific management actions prescribed by any management plan are inseparable from its management objectives, geographic region, vegetative communities, and target species, we here considered them as contextually-derived qualitative reports.

Nonetheless, forest management plans are not phenomenological accounts, despite their geographic dependence. This freed us from some of the more idiosyncratic recommendations regarding qualitative studies that cropped up in the meta-synthesis literature and allowed for the use of certain formalized systematic review techniques, most notably in defining inclusion criteria. The tools proffered by a meta-synthesis, however, were better suited towards directing the acquisition of management plans and the summarizing of thematic elements within and among plans, as discussed below. We must note that we were unable to find any previous accounts of a similar analysis as the one performed here and that our process may or may not therefore reflect best practice, but that we have attempted to adhere to the requirements of meta-syntheses as necessary and to the more scientifically rigorous process of systematic review when possible.

3.1.1 Question setting and case selection

Shofield (1990) called qualitative meta-syntheses the making of “cross-case generalizations from the generalizations made from, and about, individual cases.” To avoid overly differentiated interpretations of similar phenomena, Sandelowski et al. (1997) suggests summarizing key element across studies quantitatively. We therefore adapted a case-survey method, which uses a set of formalized questions to guide data extraction in such a way as to be easily used in statistical analysis (Sandelowski et al. 1997). To guide our case-survey of active management plans, we formulated the following primary and secondary questions:

> What wildlife management practices are commonly used by research forests across the contiguous Unites States?
>
> 1. What are the stated objectives of each forest?
> 2. What habitats and/or species are being targeted?
> 3. What management and monitoring practices are common to each forest?

Traditional search methods as recommended by systematic review protocols failed to locate any forest management plans, so we instead followed Walsh and Downe’s (2005) recommendation and contacted peer institutions directly. We identified such institutions by searching for American universities with forestry schools and associated research forests. We attempted to locate plans on the institute's website, but if plans were not publicly available, we contacted forest staff requesting their most recent management plan. In addition, we reached out to the Eastern Research Forest Managers informal network, of which Duke Forest is a member. We supplemented these forest plans with plans obtained from wildlife management agencies in the greater southeastern United States. Despite Sandelowski's (1997) recommendation to include any and all qualitative studies, the presence of significant objective physical criteria, such as use, habitat, and taxa in relation to our objectives were used to define inclusion criteria for the variety of management plans found (Table 1).

Table 1. Relevancy criteria

Relevancy Category	Action	Priorities
Forest use	Weighting	Research, teaching, education, conservation, timber, recreation, wildlife
Habitat	Exclusionary	Non-forested, upland hardwood, bottomland hardwood, pine, mixed pine-hardwood, open fields, Piedmont prairie
Wildlife	Weighting	Terrestrial, vertebrates
Outcomes	Weighting	Biodiversity, timber production, recreation use

3.1.2 Data synthesis and analysis

Initial data collection was conducted independently by two team members, and was narratorial in nature. We included forest location and size; current uses; stated goals; habitat types and dominant cover; species of interest; practices pertaining to stand, riparian, and wildlife management; and a final category for monitoring and evaluation. To further assess trends in monitoring and evaluation, we also extracted data regarding how each forest measured diversity, including any use of a specific diversity index. This qualitative data was later synthesized into broader categories that sought to highlight similar practices while distinguishing them from related categories (Sandelowski et al. 1997). Discrepancies in qualitative findings were reviewed and decided upon by a third team member prior to recording (CEE 2013).

We first analyzed management plans on a national scale, exploring the temporal and spatial aspects of all plans, and calculating the most widely represented industries. We conducted simple counts of management practices to assess commonly used practices throughout the country. To evaluate what practices were common to our geographic area of interest, we repeated this analysis using management plans from forests in the southeastern United States.

3.2 Results

We divided the US into 3 regions: West-Midwest (WMW), including all states west of the Mississippi River; North-Northeast (NNE), including all states north of Virginia; and South-Southeast (SSE), including all states east of the Mississippi and south of, and including, Virginia. We identified a total of 47 research or experimental forests (NNE = 12, SSE = 18, WMW = 17). Nineteen of these institutions had management plans available directly on the forest's website, while we personally contacted 21 institutions to obtain their plans (NNE = 5, SSE = 10, WMW = 6). Of the institutions contacted, 8 respondents supplied the management plan currently in use (NNE = 3, SSE = 3, WMW = 2) but 4 did not have a wildlife management plan (NNE = 2, SSE = 2). Of the institutions contacted through the Eastern Research Forest Managers informal network, only the West Virginia University Research Forest was able to provide a management plan. The current management plan for Duke Forest was also included in the analyses. We acquired a total of 27 management plans (Appendix A, Table A-1). Forests were further categorized by their ownership type (Figure 3).

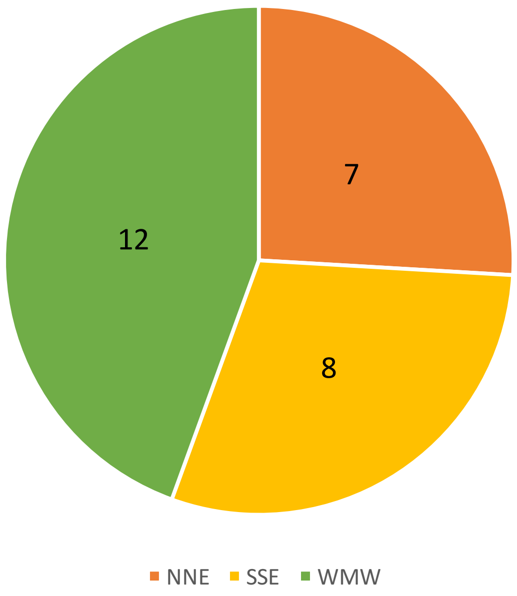

Figure 2. Frequency of management plans by region.

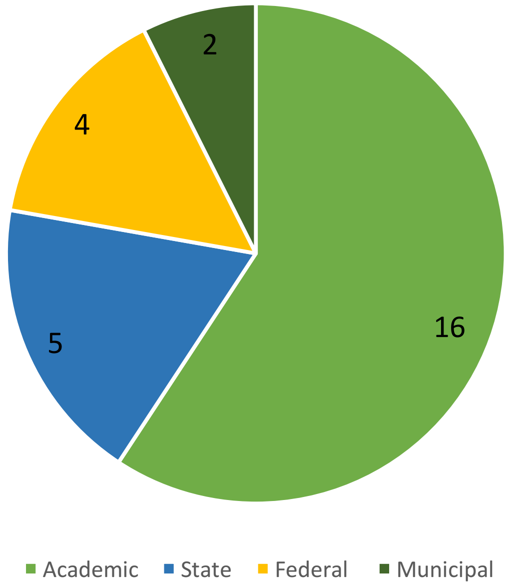

Figure 3. Frequency of management plans by ownership type.

Dates of publication for management plans range from 1983 to 2016. Three of the twenty-seven management plans had been published prior to 2000, and the average age of the plans is 8.16 years old. The forests for which management plans were obtained varied widely in size from 1,272 to 272,000 acres (mean = 24,656.6, standard deviation = 54228.2 acres, median area = 7,326 acres). Within the southeast, we evaluated 8 management plans. Forests in this region ranged from 2,680 to 70,412 acres (mean = 18,516, standard deviation = 21997.4 acres, median = 9,415.5). The average age of plans is 5.71 years old; the date of publication was unavailable for one plan. Half of the management plans were from academic forests.

We divided management alternatives into five categories: silvicultural, stand level, species specific, riparian, and monitoring and evaluation. We evaluated management practice frequency at a national scale and within the SSE region. At a national scale (Figure 4), there were no techniques used by all 27 forests. Additionally, there were also very few techniques used by a majority of forests – of the 20 total techniques that we identified, only four were used by 50% or more of the forests. The most frequently used management practice was mechanical thinning (20); supplemental habitat was used least frequently (3).

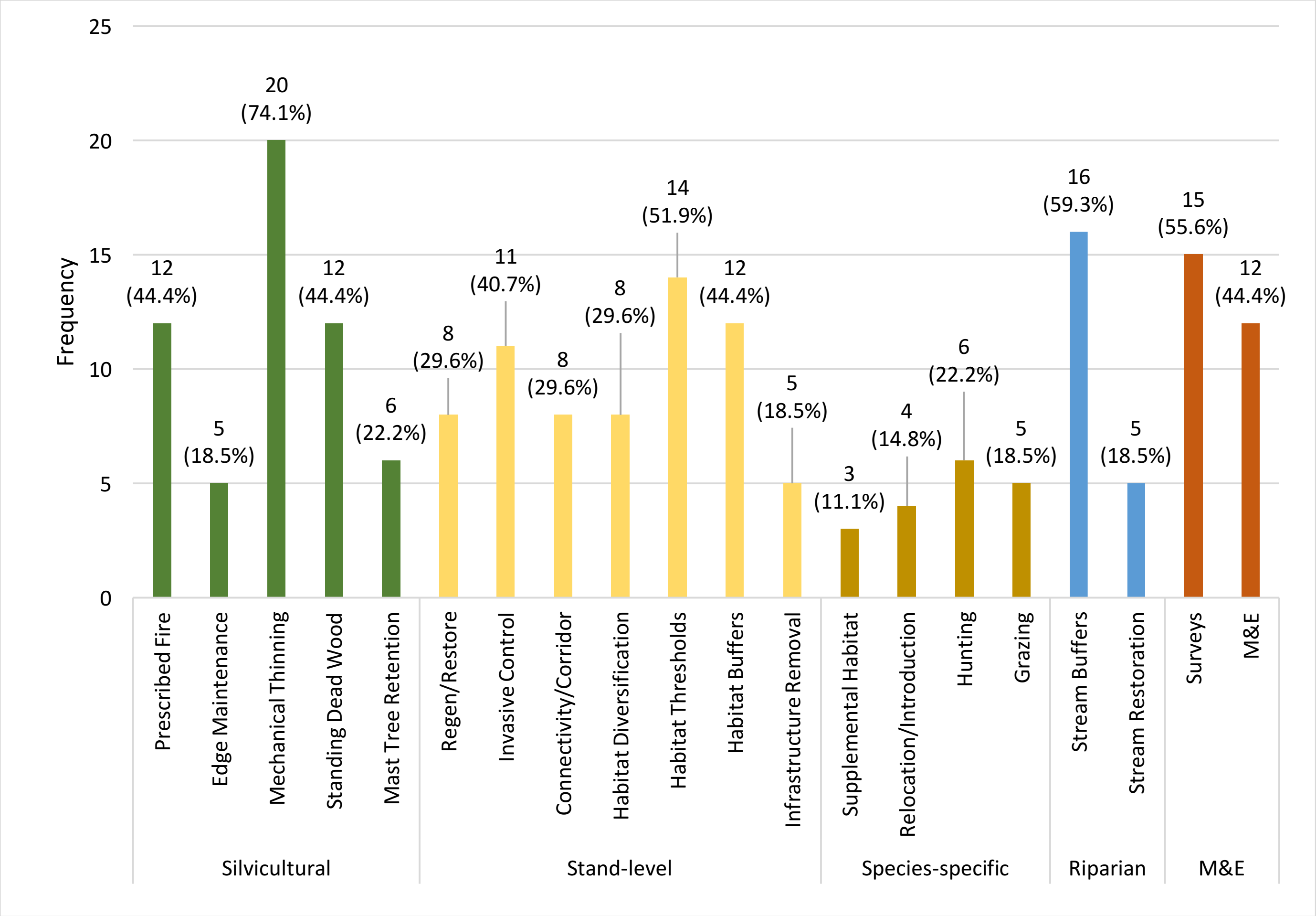

Figure 4. Management alternatives frequency, nationwide.

When we examined practices at the regional scale, we found that trends in management are not retained at the regional scale. Although mechanical thinning remains among the most frequently used practices in the SSE region (used by all eight forests, Figure 5), other practices also increased in frequency. A higher proportion of forests used invasive control (100%) and prescribed fire (87.5%) in this region than at a national level (44.4%, 40.7%). Similarly, habitat buffers, used by 87.5% of forests nationally, are among the least frequently used practices within the SSE. Grazing was not used by any forests in the SSE.

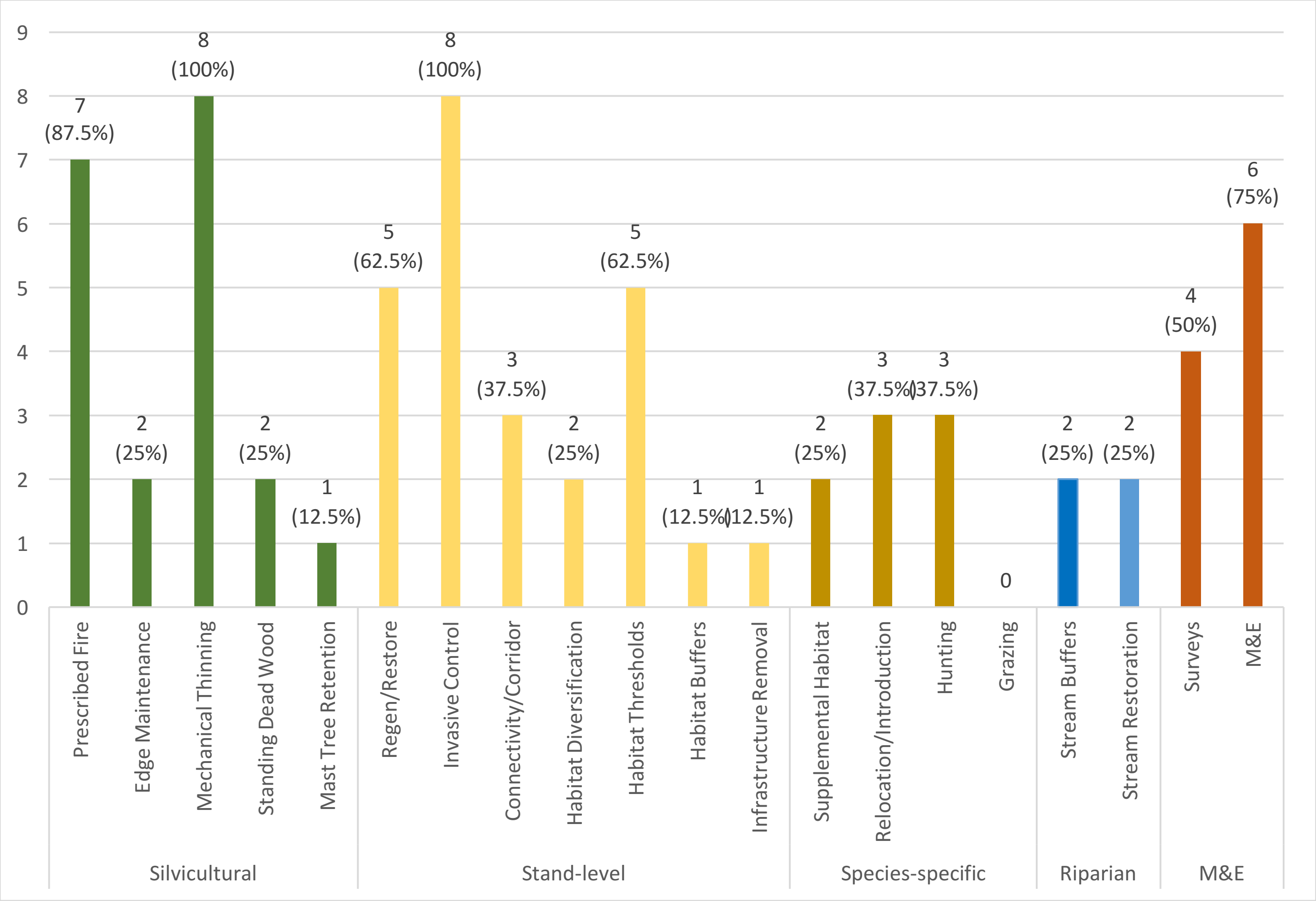

Figure 5. Management alternatives frequencies, southeast

3.3 Discussion

The breadth and distribution of management techniques are most likely reflections of the varied forest types from which management plans were sourced, indicating the highly context-dependent nature of management practices. In examining silvicultural practices, management practices meant to encourage healthy loblolly pine forests may not be appropriate for Douglas fir. Similarly, 80% of the forests using grazing as a mechanism for improving native grasslands were located in the West. This might indicate that this practice is more appropriate for improving grasslands than other practices, and would not be appropriate in other areas. Alternatively, the exclusion of this practice by forests in other regions may be because this habitat type is less prominent, or of less concern, in forests in those areas. Additionally, practices may reflect the interests of the stakeholders of the forests, such as an institutional focus of research (e.g., agriculture), or meeting long-standing grazing leases.

Other management practices may satisfy legal requirements that effect a specific geographic region. For example, the Mexican spotted owl, listed as threatened under the federal Endangered Species Act (50 CFR Part 17), is known to breed on the Centennial Forest (CITE – Centennial Forest MP). Under the ESA, the Centennial Forest is required to conduct surveys for owls when undertaking actions that may modify their critical habitat. Centennial Forest is one of only 15 forests that include surveys as part of their written management strategy. The inclusion of management practices may be influenced by legal mandates, in addition to scientific best practice, ecological conditions, and institutional research goals.

4. Assessing the outcomes of identified alternatives

4.1 Methods

Having compiled the variety of wildlife management strategies currently in use by peer institutions, we set out to investigate which, if any, of those management strategies constituted best practice as determined by peer reviewed scientific literature. To do this, we conducted a formal systematic review with associated meta-analysis. Systematic reviews, originally developed for use in medicine and public health, are a useful tool for establishing reproducible literature searches aimed at answering a specific research question through the use of a transparent, *a priori* procedure (Higgins and Green 2009). Because of their tendency to reduce bias, the process by which systematic reviews are conducted has been adopted by the environmental sciences, with appropriate alterations made to suit the idiosyncrasies of ecological data (Higgins and Green 2009, Pullin and Stewart 2006).

Systematic reviews are useful tools in collecting and quantifying data from myriad treatments with different target species across a range of habitats. They are well suited to enhancing wildlife managers' experience with empirical evidence regarding the efficacy of any management strategy, and also serve to identify any knowledge gaps that future adaptive management can address (Pullin and Knight 2001, Lortie 2014). In order to fully address these issues, our systematic review followed a series of well-defined steps: question setting, protocol development, literature searching, data extraction, and data synthesis (Pullin and Stewart 2006, CEE 2013). Data synthesis here took the form of a meta-analysis, which, while not a required component of systematic reviews, are nonetheless useful in quantifying disparate ecological data (Gates 2002).

4.1.1 Question setting and protocol development

Systematic reviews are guided by a primary question that is composed of subject, intervention, and outcome and is answerable via scientific methods (Pullin and Stewart 2006, CEE 2013). Stakeholder engagement in question setting is crucial, so that the answers sought by the question are relevant to their needs and interests (CEE 2013). Furthermore, a well-constructed question aids in defining literature search terms and inclusion criteria (Pullin and Stewart 2006). After reviewing the most commonly used wildlife management techniques from active management plans, we met with Duke Forest staff and formulated the following primary and secondary questions:

> What are the most efficacious practices to promote and maintain a variety of taxa in multiuse forests in the Southeastern United States?
>
> 1. What practices best promote diversity within relevant taxa or habitat?
> 2. How is each practice evaluated for efficacy?

Note that, while the above questions do not specify subjects or treatments, these terms are further specified in our search terms (Table 2). We also included an additional secondary question that, while not meeting the stringent requirement of a systematic review, was nonetheless of interest to our client: What is the most useful measure of biodiversity? Having established these guiding questions, we assembled a protocol (Appendix B), reviewed and approved by Duke Forest staff, that provided transparent, repeatable search and study criteria (Pullin and Stewart 2006).

4.1.2 Literature searching and data extraction

We used common management practices as determined by our aforementioned management plan review to develop our search terms, and collaborated with our client to provide regions and habitats of interest. We then conducted literature searches using Web of Science and Scopus, with the search format "management technique" AND "wildlife taxa" AND "geographic region OR habitat" (M. Peper, personal communication, September 15, 2016). Duplicate results were merged to yield a list of unique articles; these articles were then evaluated for inclusion.

Table 2. Search terms.

Management technique	**Wildlife taxa**	**Geographic region**	**Habitat**
Wildlife manag*	Mammals	Piedmont	Early successional habitat
Invas*	Birds	Appalachian	
	Amphibians		
Habitat restor*	Reptiles	Virginia	Upland hardwood
Habitat enhanc*		South Carolina	Bottomland hardwood
		Georgia	Pine
Silvicultur*		North Carolina	Mixed pine-hardwood
Harvest*			Field
Shelterwood			
Prescribed fire OR controlled burn*			Piedmont Prairie
Snag			
Mast tree			
Stream buffer			
Food plot			
Shelter			
Population control			

We limited our search to peer-reviewed articles. In the case of searches resulting in hits that proved too general, we narrowed our results by limiting our search to journals pertaining to agricultural and environmental sciences. In instances where meta-analyses had already been conducted on a subset of relevant treatments, we deferred to their findings. To address the holes identified by existing meta-analyses, we selected relevant articles using the guidelines put forward by Pullin and Stewart (2006). As per their recommendations for large-scale searches (over 1000 hits), we eliminated papers first based on title, to eliminate obviously irrelevant hits results. We then filtered papers based on abstract, and finally, the full text. Our review team for this process consisted of two members. Both members assessed each hit independently, and a third member decided in the case of discrepancies. We included papers based on their abidance to the following criteria:

1) Treatments were conducted with the objective of altering wildlife composition.
2) The indicator variable was an abundance or diversity measurement of wildlife species.

From the resulting articles, we used taxa, geography, and habitat as exclusionary criteria to eliminate studies from non-relevant species and habitats. Following Pullin and Knight (2001), we analyzed our resulting list of studies for quality using the hierarchy of quality assessment (Pullin and Knight, 2001; Table 3). We included studies from either category I or II in our final meta-analysis.

Table 3. Hierarchy of quality assessment.

Category	Quality of Evidence
I	Strong evidence obtained from at least one, properly designed, randomized, controlled trial of appropriate size
II-1	Evidence obtained from well designed, controlled trials without randomization
II-2	Evidence obtained from well designed, cohost or case controlled analytic studies, preferably from 1+ research group or center
II-3	Evidence obtained from multiple time series, or from dramatic results in uncontrolled experiments
III	Evidence inadequate owing to problems of methodology, e.g., sample size, conflicts of evidence, length or comprehensiveness of evidence
IV	Opinions of respected authorities based on clinical evidence, descriptive studies, or reports of expert committees

4.1.3 Calculating effect sizes to fill in existing research gaps

Meta-analyses are predicated on a comparison of effect sizes, which measures the magnitude of a given treatment as compared to a control. Due to low levels of replication and therefore lack of reported variance, traditional methods of calculating effect size are poorly suited to wildlife studies (Kalies, et al 2010). We instead calculated effect sizes as response ratios, defined as ln(experimental mean/control mean), as it is normally distributed and tends to reduce bias (Hedges et al 1999). Since any zero-value in the response ratio calculation would result in error, we replaced such values with 0.001, as this has been shown to result in minimal impact to overall effect size (Kalies, et al 2010).

4.1.4 Investigating the application of biodiversity metrics

To address the measure of biodiversity we conducted an informal literature search of Web of Science using keywords “comparing” AND “diversity” AND “indices” AND “review." We further refined our results by searching within the initial output for both “management” and “conservation” to exclude articles that fell outside the field of ecology. Unique papers were compiled, and data extracted from each paper regarding strengths and weaknesses of different diversity indices.

4.2 Results

After our initial searches, we had 7,982 entries in our database. After an initial round of culling by title, we had 1,426 entries. Within these results, we identified 7 meta-analyses (Appendix A, Table A-2). Compiling the results of our meta-analyses, we identified 22 unique treatments that could be broadly categorized as thinning, fire, silviculture, deadwood, and stand establishment. Stand establishment was the least studied management category, and we were unable to locate a sufficient number of studies to fill the gaps; it was subsequently discarded from further analysis.

Birds reacted very strongly in almost all categories except for those manipulations involving deadwood, where they exhibited weak-to-moderate declines (Table 4). In the case of both fire and harvesting, these effects are based on high numbers of observations. The strongest effects were on bird abundance, while species richness in most cases remained unchanged. The effects of management manipulations on mammals were much less studied, with only two effect sizes based on more than 30 samples. There were no consistent effects on mammal biodiversity across treatments. Reptiles tended to respond poorly to fire, but not significantly so. However, these results are based on relatively few observations. Observances following mechanical thinning were much higher, and support a positive and usually significant impact on reptile abundance and richness. Amphibian response to management actions are, with few exceptions, universally negative. The strongest effects resulted from high intensity fire, which greatly promoted amphibian abundance, and clearcuts, which greatly decreased amphibian abundance. Both of these findings are supported by robust sample sizes. While practically insignificant, and with small sample sizes in all cases, amphibians reacted negatively to the removal of downed woody debris and positively to its addition. Any missing effect size for management alternatives and taxa is due to its lacking peer-reviewed studies in our literature search.

*Table 4. Effect sizes of alternate practices centered around 1. Bold entries indicate effect sizes calculated using ≥ 30 observations. *Data from a linear model.*

	Abundance				Richness			
	Birds	Mammals	Reptiles	Amphibians	Birds	Mammals	Reptiles	Amphibians
High intensity fire	**6.45** **(n=268)**	1.9 (n=2)		**2.01** **(n=42)**				
Low/mid intensity fire	**3.31** **(n=161)**	1 (n=9)	0.96 (n=3)	0.94 (n=2)	**1** **(n=137)**	**0.99** **(n=33)**	0.97 (n=10)	0.97 (n=8)
Fire and thinning	**1.50** **(n=131)**	1.9 (n=40)						
Fire and herbicide	1.12 (n=7)	1.01 (n=6)	0.99 (n=2)	0.97 (n=2)	**1.01** **(n=197)**	**1** **(n=31)**	0.98 (n=4)	0.97 (n=6)
Selective Harvest	**3.9** **(n=241)**	0.9 (n=2)	0.55 (n=22)	**0.08** **(n=)**			**1.07** **(n=*)**	**0.56** **(n=*)**
Group selection cut			**1.4** **(n=36)**	**-1.12** **(n=52)**				
Shelterwood	**2.44** **(n=111)**	1.73 (n=18)	2 (n=23)	0.82 (n=60)				
Clearcut	**4.36** **(n=111)**	**1.39** **(n=122)**	**1.19** **(n=36)**	**-1.12** **(n=102)**			**1.27** **(n=*)**	**1.02** **(n=*)**
DCWD Removed	0.84 (n=13)		0.99 (n=3)	0.91 (n=3)	**0.93** **(n=57)**	1.16 (n=5)	1 (n=4)	0.97 (n=6)
DCWD Added			0.98 (n=3)	1.01 (n=3)		0.98 (n=8)	1 (n=4)	1 (n=7)
Snag Removal	0.58 (n=10)				**0.81** **(n=75)**			
Snag Addition	0.85 (n=2)		1.05 (n=6)	0.97 (n=6)	**0.85** **(n=24)**	1.02 (n=3)	1.01 (n=8)	1 (n=13)
All removed	0.61 (n=14)		1 (n=6)	0.97 (n=6)	**0.74** **(n=57)**	0.96 (n=16)	1.01 (n=10)	1 (n=13)

4.2.1 Biodiversity metric assessment

Of the twenty-seven plans examined, only Duke Forest mentioned a specific index as a metric for measuring biodiversity. Guana River explicitly mentioned quantifying wildlife as a means of assessing biodiversity, specifically utilizing species richness and abundance. While no metric of biodiversity was mentioned, two plans implied methods for assessing biodiversity: St. Mark measured biodiversity as a function of richness and abundance, and Griffith Park stated that biodiversity was assessed using richness as a result of surveys of indicator or rare species.

Only a small minority of the plans examined implied that the diversity of terrestrial vertebrates was being monitored, as they discussed biodiversity in terms of species richness and abundance. More often, we saw that biodiversity was measured in terms of habitat richness or evenness. Nineteen of the reviewed management plans used non-species diversity measurements to measure diversity. Plans that explicitly mention habitat diversity included a range of features of habitat conditions: focal species (e.g., Hemlock, Pine, and Oak in the Penobscot EF); forest age (e.g., early, mature, and old forests in the Alex Fraser Research Forest); and structures (e.g., dead wood and open fields in the Blodget Forest) were variously included as components of habitat diversity. Forests mentioned richness (14) more often than evenness (3), although those forests with a focus on evenness always mentioned richness as well. Four did not explicitly mention, but implied the use of habitat diversity as a measurement of biodiversity. Longleaf Wildlife Refuge, Swanton Pacific Ranch, Massabesic Experimental Forest, and High Tor made no mention of how biodiversity was measured, although they included biodiversity as an objective or goal.

For the assessment of biodiversity metrics, we compiled twenty-five unique papers; of these, thirteen were unrelated to any review of biodiversity metrics, and were not reviewed. As the focus of the Duke Forest is on terrestrial vertebrate species, we eliminated four papers regarding invertebrates and one paper regarding aquatic species. A technical paper on spatial statistics was also not used. The remaining papers came to varying conclusions regarding appropriate measures of biodiversity; the majority of the papers (~67%; Elliot et al 2014, Buddle et al 2005; Kellar et al 2015; Steinitz et al 2005; Jiguet et al 2012) note that sampling insufficiencies can create weaknesses in any direct estimate of diversity. Two papers (Buddle et al 2005; Kellar et al 2015) noted conflicting results when using raw species richness and single-index diversity measures. Only one paper mentioned the limitation of resources in informing the choice of index (Rodrigues and Brooks 2007). None of the papers recommended a universal measurement of biodiversity.

4.3 Discussion

4.3.1 Management affects per taxa

Management effects on birds is very well studied with high numbers of observances used to calculate the effect size, so we are fairly confident that these effects can be expected following any management manipulations the Duke Forest undertakes. Of note, bird abundance tended to be strongly affected, while species richness in most cases remained unchanged. This may be because moderate thinning intensities do not introduce new types of habitat so much as they promote existing habitat. If this is the case, we would expect declines in richness following clearcuts and high intensity thinning, which would remove most, if not all, forest habitat, and thus forest obligate species, from the management area. However, we currently lack data regarding changes in richness following high intensity fires and clearcuts; since Duke Forest does conduct clearcutting operations, this would be an excellent opportunity to investigate that effect. The negative impacts of deadwood removal, while lacking statistical power, are not surprising, as deadwood provides valuable nesting sites.

Low mammal observation rates prevent us from making strong inferences based on the available data, but given that caveat, we can say that there is no consistent effect on mammal abundance or richness across management alternatives. Moderate thinning, both via fire and mechanically, may promote mammal abundance with either no or a small negative effect on richness. We believe the same forces acting on birds are likely acting on mammals. Given the small number of observations across the board, Duke Forest should consider actively monitoring mammal populations following any management decision.

Reptile response to fire suffered from low observation rates, and the management effects here should not be taken as a definitive result. Observances following mechanical thinning were much higher, and support a positive and usually significant impact on reptile abundance and richness. This is likely due to increases in sunning locations (Pike et al 2011), but also introduces the confounding problem of detection rates. It is difficult to determine if thinning encourages increased species diversity or if the increase in sunning locations merely makes it more likely to observe rarer species. This problem also holds for any increase in abundance. Deadwood manipulations, in addition to having very low observation rates, had an inconsistent effect on reptile abundance on richness, although some research has hypothesized that the addition of woody debris, which serves as shelter for bird species, may result in a decrease in reptile populations due to predation (Riffell et al 2011).

Amphibians responded poorly to almost all management manipulations. The strongest effects, (supported by robust sample sizes) resulted from high intensity fire, which greatly promoted amphibian abundance, and clearcuts, which greatly decreased amphibian abundance. It is curious, however, that these two alternatives, which both result in a significant decrease in tree density, would have opposite effects. The positive response following high intensity fire is possibly due to the fact that many salamander species reside in underground burrows, offering them a degree of protection not afforded to above-ground dwelling taxa. The significant decline following clearcuts may be due to extensive ground disturbance caused by the heavy machinery required for such an operation. However, clearcuts had a positive, albeit insignificant, effect on species richness based on numerous sampling, which is not explained by the above hypothesis. While practically insignificant, and with small sample sizes in all cases, amphibians reacted negatively to the removal of downed woody debris and positively to its addition, likely attributable to its role in providing shelter. Finally, we must note that, more so than in studies regarding other taxa, the effect sizes for amphibians are largely derived from a few species of salamander, which may significantly narrow the applicability of our analysis.

There are no universally beneficial forest management alternatives. It is therefore necessary for Duke Forest to prioritize a specific taxa to better assess the impact of any management decisions. Especially in regard to birds and mammals, who may exhibit a greater range of habitat preferences than herpetofauna, Duke Forest should identify species of interest for more targeted management. It would be useful for Duke Forest to attempt to fill in select gaps in the literature through the application of adaptive management experiments, particularly when such a gap coincides with a management practice commonly employed in the forest, such as clearcuts or prescribed burns. Furthermore, all the taxa investigated, except for birds, suffer from small samples in calculating the effect size. Management experiments undertaken by the Duke Forest should coincide with extensive surveying before and after any treatment to provide more confidence in the strength and direction of an outcome. Because of these limitations, our wildlife management decision tool should be used as a stop-gap measure only until Duke Forest is better able to identify Piedmont species of interest.

4.3.2 Biodiversity metric assessment

Given the variety of biodiversity metrics and indices, selecting the best approach can be difficult, especially with large communities and landscapes. The first consideration must be the community being indexed. Most of the techniques mentioned in the introduction are scalable and can be applied to single guilds or to entire ecosystems. For broadly defined communities, however, we cannot assume that guild diversity in one group correlates to guild diversity in another, and so it is best to quantify the diversity of each guild separately (Moss 1979, Magurran 1988); several reviews also highlighted the importance of differentiating between indicator or non-indicator species when calculating diversity (Steinitz 2005, Elliott 2014). Land managers must consider their explicit goal in measuring biodiversity, and the resources available to collect data, as metrics vary in their ability to differentiate among sites, their sensitivity to sample size, and the precise aspect of diversity being measured. Prior use and ubiquity are also factors worth considering.

Metrics weighted towards species richness, in particular α, Q, H', and S, outperformed evenness measures in discriminating among sites (Taylor 1978, Kempton and Wadderburn 1978, Kempton 1979), while evenness measures, especially the Berger-Parker index, are robust against small sample sizes (Buddle 2005, Steinitz 2005, Magurran 1988). Similarly, indices favoring richness tend to correlate among themselves and indices favoring evenness tend to correlate among themselves, but the two families do not correlate with each other. This holds true even for those heterogeneous indices that incorporate both aspects of biodiversity (Peet 1974, Magurran 1981). Species richness, the Shannon index, and the Simpson index are perhaps the most commonly used, and therefore widely understood, diversity metrics, but both α and the Berger-Parker index are increasing in popularity (Magurran 1988).

There is no universally applicable diversity metric that provides an accurate assessment of biodiversity. Each stresses a different aspect of diversity and comes with inherent strengths and weaknesses. It is perhaps more helpful to think of the variety of metrics as being complementary. Richness indices are very useful in distinguishing among sites, but are highly sensitive to sample size. However, evenness indices are highly robust to sample size while lacking in discriminant abilities. For the most complete picture of diversity, the two should be used in conjunction. If data exists to construct an abundance distribution, α is the best indicator of species richness, as it is robust against small sample size and easy to calculate. Barring this, species richness S is a suitable alternative. Either can be complemented with the Berger-Parker index, an easily calculated metric that provides an assessment of evenness. The Shannon index, while commonly used, is relatively mediocre in its ability to discriminate among sites and its sensitivity to sample size, fails to accurately reflect underlying abundance distributions, and lacks any direct biological interpretation (Elliott 2014, Goodman 1975, May 1975, Magurran 1988, Steinitz 2005).

Many of the review papers touched on the fact that different biodiversity indices would be appropriate for different settings or purposes, but we were surprised that only one touched on the idea of a pragmatic index, or that the appropriate index would be the one that could be used given very limited resources. Other papers talked about how insufficient sampling could be a weakness, but did not explicitly state that insufficient sampling would be the rule, and not an exception (e.g., insufficient sampling would always be the case, given the dearth of resources for monitoring and evaluation). The only paper to acknowledge that limitation would inform the metric of choice did so while examining the efficacy of using surrogates, such as environmental data (Rodrigues and Brooks 2007). As habitat diversity was the focus of a majority of the management plans, we were surprised that it wasn't mentioned more often in the reviews, especially given the stated weaknesses and limitations of indices weighted towards species richness.

Habitat diversity in working forests is not only a matter of conservation, but a very practical concern in terms of timber harvests, as these have important financial implications. Duke Forest, for example, does not maintain continuous records of vertebrate surveys, but does have more than twenty years of continuous data regarding the habitats within its stands, and more sporadic data from as far back as 1931, including information on age, species, and structures within managed stands, as well as plans for forty years into the future (DFMP 2015). Monitoring habitat diversity requires very few resources from a working forest. Working forests keep these records as a part of their timber management goals; because they are already being kept coincidentally, they can be easily used to inform goals regarding biodiversity. It is, therefore, an appropriate measurement for a working forest.

In choosing an appropriate diversity metric for the Duke Forest, we must examine both the objectives of the forest and the resources available. Given the limited resources, measuring wildlife species richness or evenness would be far too labor intensive; instead, we recommend using a measure of habitat diversity. Using both richness and evenness indices of habitat diversity may provide both strengths and weaknesses when used at different scales within the forest. Assessing richness is necessary to ensure that all native Piedmont habitats are represented within the Duke Forest as a whole; however, given the sizes of some of the smaller divisions, ensuring a high richness in all divisions may not be feasible. As a substitute, evenness indices may be used at smaller scales – while they lack in distinguishing abilities among sites, they would be well-suited in assessing the habitat diversity across divisions.

A key aspect of this approach would be to focus on distribution of habitat, and focus on proportion within divisions; a balance would need to be found between having contiguous habitat and having even habitat distribution within a division. Limitations of this approach would become apparent if comparisons of habitat diversity were made across the divisions of the forest. Using richness indices in conjunction with evenness indices will serve to mitigate this weakness, and complement both approaches. Richness will provide a more accurate reflection of biodiversity within the larger Duke Forest, while evenness will be more robust against small sample sizes.

A final consideration that must be made is the desired diversity index of the managers of the Duke Forest. Familiarity from their previous use of the Shannon index, as well as any changes in resources in the near future, may influence the index they decide to use in the management plan; they may also decide that a focus should be made on habitat diversity within divisions of the forest, rather than on the forest as a whole. With these considerations in mind, we recommend that habitat evenness be the metric used for the next Duke Forest Management Plan.

5. Gauging client satisfaction

5.1 Methods

As the effect sizes we compiled did not all share the same center value, it was necessary to standardize them. We opted for a categorical classification scheme (Table 5) to make determining relative satisfaction more straightforward for our client. Due to varying sample sizes, confidence interval widths, and methodological differences, statistical significance could not be compared. Below readings of 'significant' should be interpreted as practical rather than statistical. Duke Forest staff then assigned a satisfaction level to each outcome as a function of the least desired outcome relative to the most desired outcome, and weighted a preference for abundance versus richness in a similar fashion (Maguire 2014). We then conducted a sensitivity analysis to explore how varying satisfaction levels affected each management alternative's score. Finally, we calculated scores for each management alternative by multiplying the relative satisfaction of each outcome by the weight given each component of biodiversity (Maguire 2014). We decided against using placeholders for missing data to preserve transparency in the final product. As such, categories that contain no data will be calculated as if they resulted in the worst outcome.

Table 5. Effect size categorization.

Category	Threshold	Impact on biodiversity
+++	>1 above center	Large and significant increase versus control
++	0.26-0.99 above center	Small but significant increase versus control
+	≤0.25 increase above center	Small and insignificant increase versus control
0	No change from center	No effect
-	≤0.25 decrease below center	Small and insignificant decrease versus control
--	0.26-0.99 decrease below center	Small but significant decrease versus control
---	>1 decrease below center	Large and significant decrease versus control

5.2 Results

In seeking to promote biodiversity, staff of the Duke Forest chose to emphasize community richness (0.7) over species abundance (0.3). They also opted for a relative satisfaction scheme that was extremely dissatisfied with losses in biodiversity but improved steadily as biodiversity increased (Table 6). This resulted in relatively low levels of satisfaction up until the point where there was a large and practically significant increase in biodiversity. Choosing different satisfaction schemes (Figure 6) would have altered the final score of each alternative, but not necessarily the alternative’s ranking in relation to other alternatives.

Table 6. Client satisfaction per outcome. Satisfaction ratings reflect client’s desire to maximize increases in biodiversity.

Category	Description	Relative Satisfaction
+++	Large and significant increase in biodiversity versus control	1.00
++	Small but significant increase in biodiversity versus control	0.50
+	Small and insignificant increase in biodiversity versus control	0.30
0	No effect in biodiversity	0.20
-	Small and insignificant decrease in biodiversity vs control	0.10

--	Small but significant decrease in biodiversity versus control	0.02
---	Large and significant decrease in biodiversity versus control	0.00

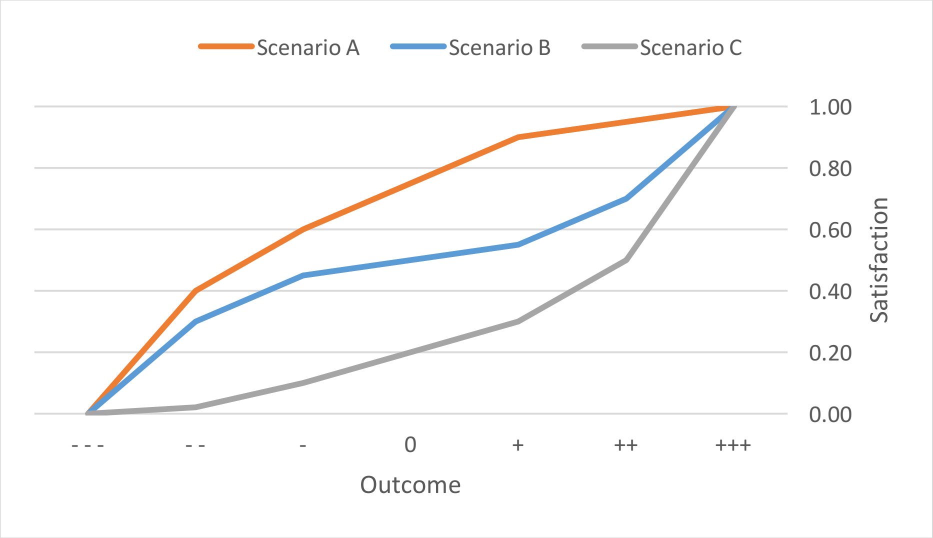

Figure 6. Satisfaction sensitivity. Scenario A depicts a scheme that is satisfied with any outcome that does not drastically reduce biodiversity, scenario B one that seeks to avoid major decreases or encourage major increases, and scenario C a situation that ties satisfaction to the proportional increase in biodiversity. Duke Forest selected a scheme similar to scenario C.

5.2.1 Conducting a decision analysis

Given our client's prioritization parameters, any alternative with a final score above 0.2 is one that promotes biodiversity, either by increasing species abundance or community richness (Table 7). There are no alternatives that universally promote biodiversity across taxa, although clearcuts come closest, increasing diversity in all taxa except mammals. The lowest scoring alternatives are combination fire and thinning, group selection cut, and snag removal. Note that these scores do not distinguish between detrimental practices and those categories lacking data. Detailed decision tables for each taxa are located in Appendix C, along with instructions for using the adaptive decision tool**.** Our decision analysis was largely insensitive to changing satisfaction schemes, resulting in only one instance where our client's preferred satisfaction suggested an alternative different than the other two schemes.

Table 7. Final management alternative scores, as calculated by multiplying performance weight by outcome satisfaction. Bolded scores are those that increase biodiversity.

		Score			
		Birds	Mammals	Reptiles	Amphibians
Prescribed fire	High intensity fire	**0.30**	0.15	0.00	**0.30**
	Low/mid intensity fire	**0.30**	0.13	0.10	0.10
	Fire and thinning	0.15	0.15	0.00	0.00
	Fire and herbicide	**0.30**	**0.23**	0.10	0.10
Mechanical Thinning	Selective Harvest	**0.30**	0.03	**0.22**	0.08
	Group selection cut	0.00	0.00	0.15	0.00
	Shelterwood	**0.30**	0.15	**0.30**	0.03
	Clearcut	**0.30**	0.15	**0.44**	**0.21**
Deadwood manipulation	DCWD Removed	0.10	**0.21**	0.17	0.10
	DCWD Added	0.00	0.07	0.17	**0.23**
	Snag Removal	0.08	0.00	0.00	0.00
	Snag Addition	0.10	0.21	**0.30**	0.17
	All removed	0.04	0.07	**0.27**	0.17

6. Community-based monitoring

6.1. Methods

To understand the potential benefits, challenges, and best practices of using Citizen Science as a monitoring tool in the Duke Forest, we conducted interviews with citizen science practitioners and a systematic review. More specifically, we interviewed practitioners on the forefront of actively using citizen science in adaptive management approaches. This was conducted in conjunction with a systematic review of best practices to determine if community based monitoring would be an appropriate tool to use in the wildlife management plan for Duke Forest.

6.1.2. Subject Selection

Subjects interviewed were limited to those actively using citizen science to make management decisions, as well as experts and active citizen science program leads. These subjects were initially identified at a citizen science Symposium held at Duke University in spring 2016. From there, snowball sampling was used to identify more individuals who would be able to add additional insights to our investigation (Kowald and Axhausen, 2010). New subjects were identified throughout the continental United States until we began receiving repeated suggestions of people to speak with and had to end subject selection due to time constraints.

6.1.3. Interview guide and questions

With the help of a social scientist professional (Dr. Randall Kramer, Duke University), we compiled a list of 10 guiding questions. From November 17th, 2016 through February 10th, 2017 we conducted semi-structured interviews using some guiding questions. The following are the 10 guiding questions we used to frame our interviews:

1. How do you currently use citizen science within the wildlife management plan for your organization?
2. What is the aim of your management plan (i.e. endangered species conservation, retaining high biodiversity, etc.)?
3. What species do you use citizen science to manage?
4. When did you start using citizen science and why?
5. What do you see as the advantages of incorporating citizen science as compared to other techniques? In your opinion, how valuable is citizen science relative to other types of information on a scale of 1-5, with 5 being very valuable.
6. What has not worked well for you when using citizen science (any downsides)?
7. Is your citizen science approach written into a formal management plan?
8. Which apps (if any) do you use and how does this data integrate into your management of target species?
9. Do you have any suggestions about incorporating citizen science into an adaptive wildlife management plan?
10. Is there anyone else you think would be of value for me to speak to about using citizen science to manage for wildlife?

(Before the data collection process could begin, an IRB exemption form was approved.)

6.1.4. Interview coding process

To evaluate the interviews, we implemented a basic coding system to assess how often similar responses were present, as well as any responses that jumped out as different or particularly useful (Bazeley, 2013). Those codes within varying subjects were tallied up and are the base of our recommendations for potential citizen science implementation, depending on where the best uses of citizen science overlap with the goals for Duke Forest. We chose a simplified coding process as there is no single correct way to code data and analyze qualitative data (Dierckx de Casterlé et al., 2013). This consisted of tallying themes and specific wording across all interview responses.

6.1.5. Systematic Review

Upon completing the interviews, a systematic review was performed to fill any gaps missing from the interview information (see guidelines in section 4.1). We set out to answer the following two questions:

1. How are scientific papers using citizen science collecting data?
2. What quality assurances practices are being implemented by scientists publishing research using citizen science data?

We used the information from interview responses (i.e., specific wording and key terms that kept recurring in interviews) as a basis for the search terms for the systematic review. The searches were conducted by using one term from each category (Table 8) and due to the relatively new nature of citizen science use, limited to the past 50 years. The databases queried were Scopus and Web of Science.

Using Zotero, all duplicates and irrelevant articles were discarded, leaving only the most applicable articles. Applicable articles directly explained positive or negative aspects of using citizen science as a monitoring tool, data quality measures, or explicitly explained how they implemented citizen science data quality assurances (case studies) in monitoring or evaluation of species. Overlapping the results from the systematic review and the interviews, we established recommendations for possible uses of citizen science within the Duke Forest.

Table 8. Search criteria for community monitoring systematic review.

Citizen	Science
Volunteer	Data
	iNaturalist
	Biology
	Ecology

6.1.6. Multi-Criteria Decision Analysis

We implemented the use of a multi-criteria decision analysis (MCDA) to come up with specific recommendations for the Duke Forest. Using the results from the interview data and literature regarding community based monitoring practices, goals and needs, a decision table was created (see results). Such a decision table is utilized to compare tradeoffs across various alternatives and stakeholder objectives. To begin, we used some of the main themes that arose during the interviews as well as the literature to determine (1) alternative objectives for citizen science programs, (2) requirements for a community-based monitoring program and (3) best practices for data quality assurance measures. We then had the Duke Forest staff rank their priorities and the resources they could give to each objective and requirement.

Table 9. The six main program requirements (a) and the four main objectives (b) that were ranked by the Duke Forest Staff.

(a) Program Requirements
Training
Program Design
Protocol
Money
Time (once program is established)
Time (set up)

(b) Main Objectives
Conservation of known populations in the DF
Public outreach/involvement/education
Enhancing knowledge of the biodiversity present in DF
Low amount of resources required from DF

From there, we came up with three alternative monitoring schemes to rank based on the weights (W) obtained by the stated priorities from the Duke Forest staff and the performance scores (U) from the interview and literature data. For the performance score, the number of individuals who discussed a particular performance metric alternative was divided by the total number of individuals we interviewed. Similarly, if the data was from the literature, the number of papers where the aspect was discussed was divided by the total number of papers. The only exception for this performance score calculation method was in the case of deciding which species or environmental factor to monitor. Here, we still used the ranks stated by the Forest as the weights, but used a performance score based on whether data for each environmental factor is needed, specifically at the Duke Forest. Several of the environmental factors listed already have monitoring programs in the Duke Forest, so it would not be useful to create a second program. Multiplying the stated weights and the performance scores, we obtained an overall utility score, where the highest overall utility is the recommended option.

$$U=W_1*U_1+W_2*U_2+...W_n*U_n$$

This equation used to obtain overall utility between alternatives assumes linearity, although this may not always be the case.

6.2. Results

We contacted a total of 24 subjects, 18 of whom were interviewed between November 11, 2016 and February 10, 2017. Subjects were interviewed across 7 states throughout the United States, with an emphasis on North Carolina to ensure that local practices were highlighted. This also led to creating local contacts and including as many statewide citizen science programs and experts as possible (Figure 7).

Of the 18 individuals we interviewed, a wide variety of taxa and general environmental factors were reported as being monitored by a citizen science program (Figure 9). Many of the subjects were running multiple citizen science programs, and some projects had studied by citizen science focused on mammals.

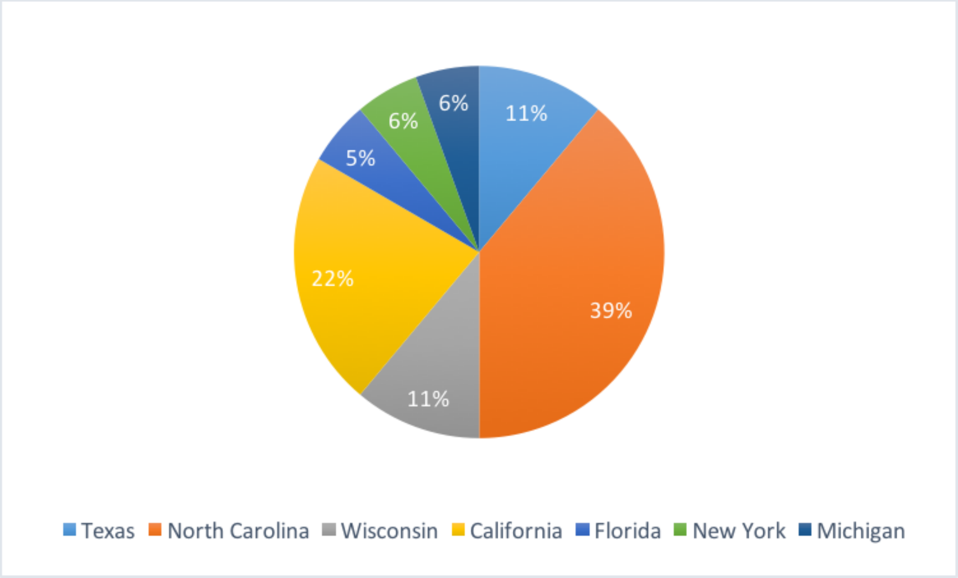

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Figure 7. Locations of the individuals interviewed for data collection across the 7 states

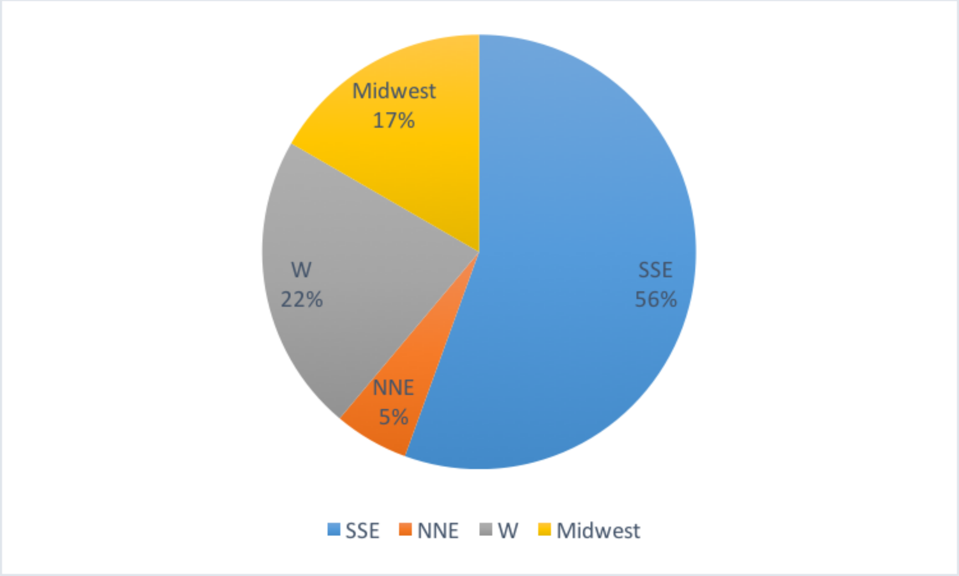

Figure 8. Regions of individuals interviewed.

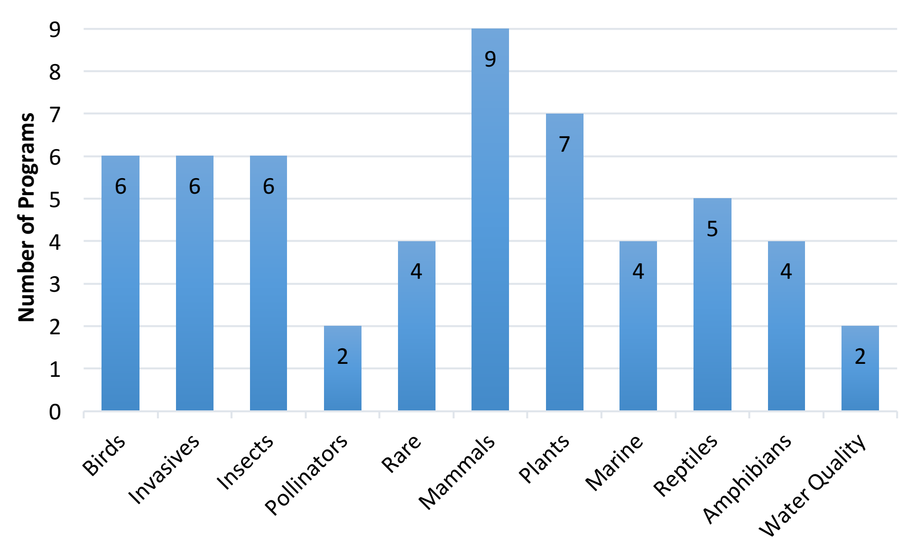

Figure 9. Reported programs of species and other environmental factors monitored through citizen science efforts.

Within the monitored environmental factors, we also asked subjects which technologica; applications or data collection techniques they used, if any (Figure 10). The most widely used (44%) smartphone application reported was iNaturalist, likely due to the wide variety of taxa it is set up to monitor. Five people (28%) also reported creating their own website or smartphone application for a specific project that they used instead of an existing platform. Other reported `smartphone applications included Nature's Notebook, Picture Post, Journey North, Last Ladybug, Marine Debris Tracker, ArcGIS collector, and Zooniverse. Websites were mostly created for specific projects, although some, such as Wildlife Picture Index, were reported by several as a pre-developed website that people used to go through camera trapping photographs.

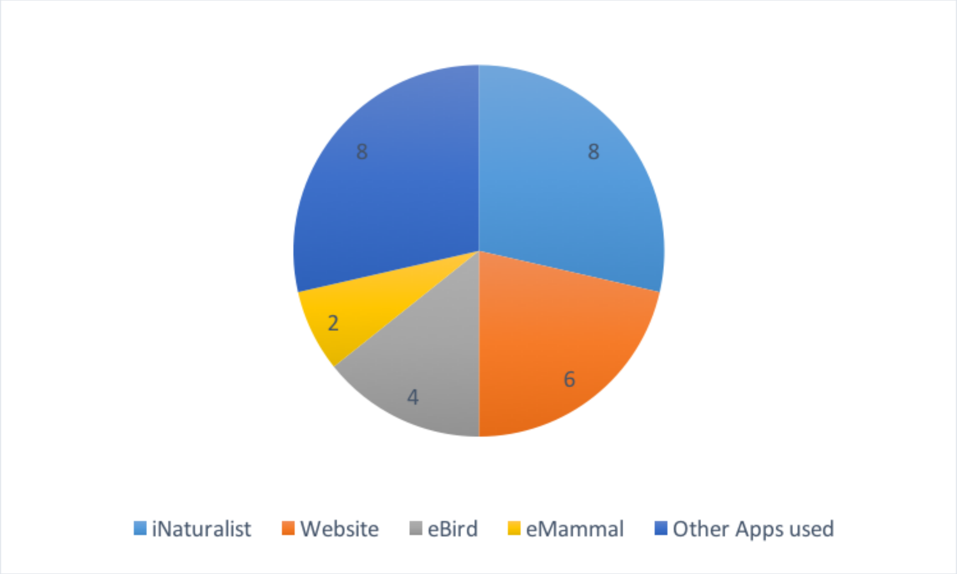

Figure 10. Different alternatives for data collection within citizen science platforms.

The most commonly reported benefit of using citizen science was increased public engagement, mentioned by 67% of subjects. Second to that, the cost-effective nature of citizen science projects was another advantage of using citizen science over other data collection techniques, as reported by 44% of the respondents. Some unique benefits were stated by one or two subjects, such as the ability to survey private land and "increasing the creative thinking power of a project." Witnessing social change within the project community was another interesting benefit. Technically speaking, some other program design benefits included 17% who reported consistent involvement over time (the same volunteers return year after year) and 28% who reported the large scale (both spatial and temporal) when using volunteers as compared with hired professionals. Four respondents (22%) described community-based monitoring as a very good "alarm system," as the individuals involved in these projects often know the area so well that if anything is amiss, they will know immediately. Finally, 8 people (44%) said citizen science is a "very good tool to observe changes in trends over time", as one interview respondent described it.

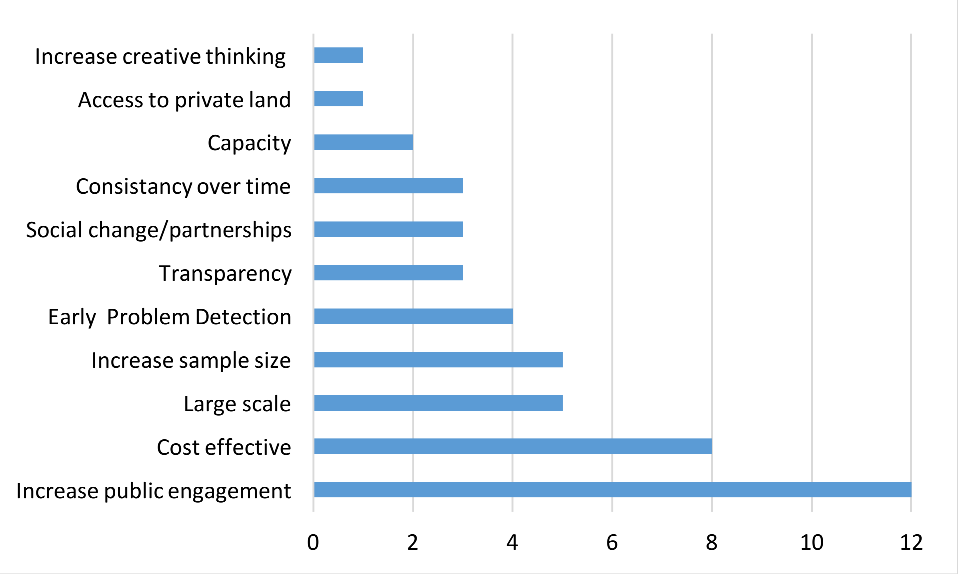

Figure 11. Reported benefits from using community-based monitoring.

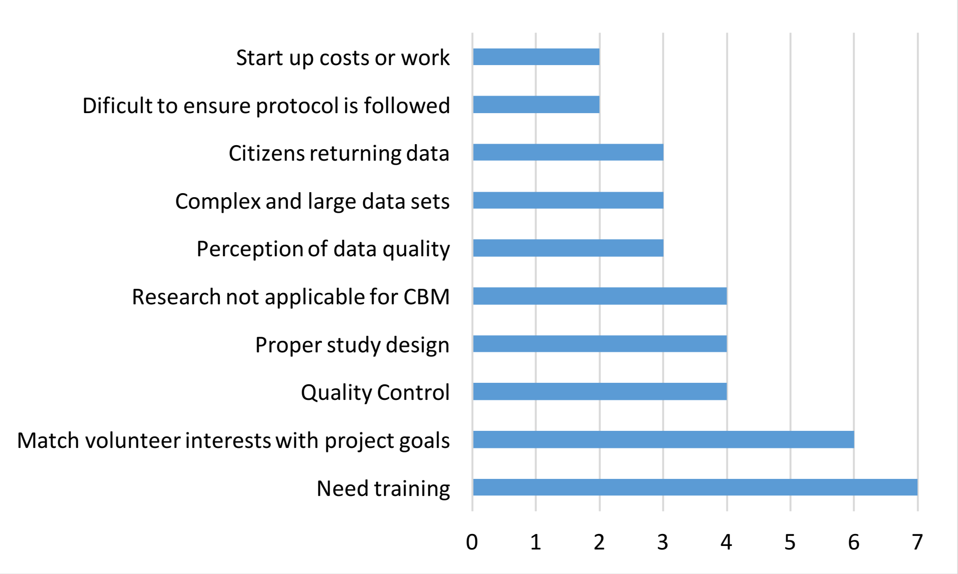

Figure 12. Reported challenges of utilizing community-based monitoring.

As far as disadvantages, several recurring issues surfaced. The most reported challenge (39%) was the need for proper training to ensure a successful program. Secondly, making sure the project goals align with volunteer interests arose (33%) as an issue related to volunteer retention and data quality. Also of interest was that only 22% indicated that data quality was an issue, and only 17% stated that the perception of data quality was a greater challenge than the actual quality. One subject said his main challenge was that when you are not paying people for their work, you are giving up a lot of control. Of course, several people (22%) were also very clear that some projects require too much expertise, detail or time and therefore are not a good match for a citizen science program.

An important question we asked, but that was not possible to code quantitatively, but incredibly valuable for the Duke Forest; "Do you have any suggestions about incorporating citizen science into an adaptive wildlife management plan?". This resulted in a wide variety of responses, but some of the main themes that arose were the following:

1. Start small (with both the number of people involved and the aim of the project. Begin with one species and one platform)
2. Have a clear objective with goals set at the beginning.
3. Use pre-established resources (existing platforms and ask for help from professionals)
4. Find out why individuals are volunteering and focus the program to ensure people are getting what they want out of participating.
5. Be sure to collect effort data.
6. Share results. (28% of respondents stressed the importance of sharing interesting findings with the volunteers)

6.2.2. Assessing data quality

Upon completion of the primary article search in Scopus and Web of Science, a total of, 1437 articles were identified. After merging duplicate items, 1057 articles remained. We determined the remaining articles based on the previously listed criteria, a previously published systematic review in 2015 by Lewandowski et al. guided a new set of 51 articles. We eliminated any articles published prior to 2014 and modified our goals to try to address any gaps in the research of the previously conducted systematic review addressing data quality issues in citizen science projects. Once the remaining 51 articles were closely investigated, a total of 24 remained for the final analysis. Five additional articles specifically investigated effects of volunteer and project characteristics on data quality, adding additional recent publications to the findings of Lewandowski et al. (2015). One other investigated such attributes on general participation instead of quality and another looked at such characteristics with likelihood of a study getting published. Table 10 is modified from table 3 of Lewandowski et al. (2015) with the 5 additional articles included.

The predictors of volunteer characteristics on data quality led to some additions to Lewandowski et al. (2015). Reported by Lewandowski, volunteer education was found to have an effect on data quality by 3 of 5 articles. Our additional data revised that to show that 50% of the articles found it had an effect and 50% did not.

Table 10. Combined findings from Lewandowski et al. (2015) and articles published since 2014 that were not included in the earlier analysis.

	Effect of Predictor		
Predictors of volunteer data quality	*Yes*	*No*	Total
Prior knowledge	67%	33%	46
Repetitions of method	83%	17%	6
Education	50%	50%	6
Training	83%	17%	6
Fitness	50%	50%	4
Age	0%	100%	4
Gender	67%	33%	3
Mental aptitude	100%	0%	2
Motivation	0%	100%	2
Group size	0%	100%	2
Positive feedback	100%	0%	1
Site faithfulness	100%	0%	1
Technology used	100%	0%	1
Instantaneous NLG feedback	100%	0%	1
Computer expertise	100%	0%	1

The remaining 19 articles (Table 11) addressed quality within citizen science data (not including the project and volunteer component quality predictors). These articles gave the consensus that with proper protocol, training, set verification and time, citizen science data can be trustworthy (Kamp et al 2016, Crall et al. 2015, Fuccillo et al. 2014). Other techniques such as ignorance scoring proposed by Mair and Ruete (2016) and having experts train volunteers (Turnhout et al. 2016) are good for project data assurance as well. Vanderwal et al. (2015) also have experts confirm identification in a study researching pollination. Many people argue that citizen collected data is in fact just as good as professional scientific data, and potentially even more reliable, due to the many data quality assurance measures. (Lewandowski et al., 2015).

Table 11. Articles in which data quality measures occurred but were not analyzed as the focus of the paper.

Mechanisms to improve data quality	**Number of papers where method is used or recommended**	**Percent of total papers**
Protocol	6	32%
Expert involvement	5	26%
Statistics	4	21%
Training	4	21%
Removal of suspect data	4	21%
New Technologies	4	21%
Study design	3	16%
Transparency/easy tasks	3	16%

Cross-check data	3	16%
Frequency-sampling strategy	3	16%
Time	2	11%
Site selection	2	11%
Skilled volunteers (prior experience, students)	2	11%
Sub-sample confirmation	1	5%
Close ended Questions	1	5%
Ignorance Scores	1	5%

6.2.3. Multi-Criteria decision analysis

Based on the results from the interviews on program components and recommendations as well as the literature to assess data quality measures, we compiled a decision matrix. The Duke Forest staff then ranked the options under four main categories; environmental factors to monitor, goals of the monitoring scheme, potential tools within a program, and amount of resources they are willing to provide. For the list of environmental factors (Table 12) the Forest would be interested in monitoring and managing, reptiles, amphibians and rare species were rated the highest. One point here is that rare species may overlap with any other taxa.

The logistic alternatives (Table 13) deemed as the best for the Duke Forest to implement through the MCDA process were (1) involving the entire public, followed by using (2) a free smartphone app (the two highest overall utility scores). After that, the next best alternatives were collaborating with other organizations, using a non-free smartphone app, and increasing the public engagement in the Duke Forest. However, since using a free smartphone app was in the top alternatives, the use of a non-free app should not be considered as a good alternative if a free application is possible. It is also of note that the overall utility score of matching project goals with volunteer interests is one of lowest overall utility scores (0.0165) but one of the higher performance scores (0.33).

Implementation feasibility was the final alternatives table we compiled (Table 14), in which the amount of resources the Duke Forest is willing to provide for each of the alternatives was rated. Training received the highest overall utility score at 0.21. Following training, the amount of time to set up the project was the second highest overall utility (0.1). Third was protocol, but at a low score of 0.02. As for the amount of money the Duke forest is willing to provide for a citizen science program, they stated a medium amount. However, from our data we were unable to arrive at a reliable performance score for this attribute, so it was excluded from the remainder of the analysis.

Table 12. Performance scores, stated weights and normalized weights for environmental factors for the Duke Forest to potentially monitor. Normalized weights were multiplied by performance scores to obtain the overall utility scores.

Monitoring	Priority (Performance)	Weights	Normalized Weights	Overall Utility
Birds	1	90	0.126	0.126
Mammals	1	90	0.126	0.126
Reptiles	1	100	0.140	**0.140**
Amphibians	1	100	0.140	**0.140**

Habitat composition change	0.5	75	0.105	0.052
Water Quality	0	10	0.014	0.000
Rare	1	100	0.140	**0.140**
Invasives	0	0	0.000	0.000
Insects	0	70	0.098	0.000
Phenology	1	80	0.112	0.112

Table 13. Different alternatives for program design components within citizen science platforms.

Logistics (alternatives)	**Weights**	**Normalized Weights**	**Performance score**	**Overall Utility**
Using an app (free)	1	0.1	0.75	**0.075**
Using an app (not free)	0.5	0.05	0.75	0.0375
Using a website	1	0.1	0.18	0.018
Using photography	1	0.1	0.28	0.028
Match project goals with volunteer interests	0.5	0.05	0.33	0.0165
Collaborate with other organizations	1	0.1	0.39	0.039
Statistical analysis	1	0.1	0.21	0.021
Involving entire public	1	0.1	1	**0.1**
Involving students (environmental field)	1	0.1	0.11	0.011
Involving Experts	1	0.1	0.26	0.026
Increased public engagement in DF happenings	1	0.1	0.33	0.033

Table 14. Resources required to implement a citizen science program and the weights as stated by the Duke Forest. Here, the weights indicate the amount of that resource the Duke Forest is willing to provide (high {0.9}, medium high {.75}, medium {0.5}, medium low {0.25}, and low {0.1}).

Implementation Feasibility	**Performance**	**Weights (0-1)**	**Normalized Weights**	**Overall Utility**
Training	0.83	0.5	0.26	**0.21**
Time for project set up	0.39	0.5	0.26	0.10
Time once project has started	0.06	0.25	0.13	0.01
Money		0.5	0.26	
Protocol (takes time)	0.32	0.1	0.05	0.02
Program Design (takes time)	0.22	0.1	0.05	0.01

To assess a specific potential community-based monitoring program, we took the stated satisfaction scores (Table 15) and multiplied them by the utility scores (Table 16) based on how well that program would perform for each of the alternative outcomes and needs. The values were determined by assessing the information from the interviews and literature. From this data, the three alternatives were rated across how well they performed for each objective. The objectives were rated as either performing as low (0.1), medium (0.5) or high (0.9) for each of the three alternatives. The final table (17) shows the multiplied weights and utility scores for each objective across alternatives. Based on these calculations, the Duke Forest should implement a long-term existing community-based monitoring program.

Table 15. Stated satisfaction scores as weights for each objective as declared by the Duke Forest staff. Weights were normalized via ratios to total to 1.

Objectives	Weights (0-100)	Normalized Weights
Conservation of known populations in the DF	90	0.391
Public outreach/involvement/education	50	0.217
Enhancing knowledge of the biodiversity present in DF	80	0.348
Low amount of resources required from DF	10	0.043

Table 16. Utility scores for each of the four objectives across the three alternatives. Objectives are rated low (0.1), medium (0.5) or high (0.9) based on how well the objective performs for each of the three alternatives.

Objectives	Bioblitz	Existing program (long-term)	New program (long-term)
Conservation of known populations in the DF	0.1	0.9	0.9
Enhancing knowledge of the biodiversity present in DF	0.9	0.9	0.9
Public outreach/involvement/education	0.5	0.9	0.5
Low amount of resources required	0.5	0.9	0.5

Table 17. Decision matrix to determine the highest scoring option for a potential program based off Duke Forest's stated satisfaction and the performance of the program traits.

Outcomes/Needs	Bioblitz	Existing program (long-term)	New program (long-term)
Conservation of known populations in the DF	0.039	0.352	0.352
Enhancing knowledge of the biodiversity present in DF	0.313	0.313	0.313
Public outreach/involvement/education	0.109	0.196	0.109
Low amount of resources required	0.022	0.039	0.004
Overall Utility Scores:	0.5	**0.9**	0.778

6.3. Discussion

Some important findings for the Duke Forest regarding possible implementation of a community-based monitoring program involve the overlaps between what the Forest is interested in and willing to provide and what a program could provide. Based on the results for a good quality program with high quality data, proper training is required. The Forest has stated that they are willing to provide training, which is promising for the implementation of a successful community-based monitoring program. However, the low amount of resources the Forest would be willing to provide for establishing a protocol does not align with the need for a clear protocol for a successful program with high quality data. We therefore recommend utilizing a program with a pre-established protocol rather than creating a new program for the Forest. Another issue the Duke Forest may face is their low interest in matching volunteer interests with project goals. When using volunteers, some control over the project is given up as a tradeoff for not paying the participants. Therefore, the Forest will need to reconsider this concept if a community-based monitoring program is to be implemented.

Some considerations involving the data collection should be given to the bias present in snowball sampling. This method involves utilizing the social network of past participants, so this narrows the potential number of interview subjects. This bias of snowball sampling, in addition to the potential bias of only interviewing individuals in the citizen science profession has some implications for the data; however; this is not a substantial issue given the nature of this study. Additionally, the MCDA process inherently requires some over simplification in order to create categories for alternatives and objectives. Further investigation into the objectives and increased detail of actual program requirements, particularly monetary needs, should be considered further in future studies. Money was not included in this analysis, though it is one key requirement for a citizen science program. Another consideration within the final MCDA is how to focus the overall utility scores between the two long-term program alternatives. A sensitivity analysis should be performed before any final decisions of program implementation are made.

7. Recommendations

7.1 Wildlife management approaches

Promoting biodiversity through habitat diversification:

- **Identify habitat types appropriate for the Piedmont.** Duke Forest currently divides habitat into nine classifications based on Evans' (1974) assessment of ideal habitat distribution for the Missouri Ozarks. We recommend these habitat types be updated to better reflect native Piedmont habitat types, which include, but are not limited to, dry coniferous woodlands, early successional, and mesic forests (Scafale and Weakley 1990).

- **Promote habitat diversity at multiple scales.** Because of the non-contiguous nature of Duke Forest, habitat should be managed at both the forest and the division scales. This would mean taking steps to ensure that all relevant habitats are represented in the Forest, but not necessarily in each division, and that each division contains as diverse an assortment of habitat as is feasible given its size.

    - To determine whether Duke Forest reflects the greater Piedmont region, Forest staff will have to establish habitat thresholds, likely as a percentage of total acreage or number of parcels, that are consistent with either historic Piedmont composition or modern distribution. Soil maps of the Duke Forest may provide valuable insight into the optimal habitat distribution. Whichever composition they choose to manage for will need to be supported by extensive further research. Establishing habitat thresholds will ensure that Duke Forest fulfills its overall mission of promoting diverse animal communities across the Forest.

    - Individual divisions should be managed such that they are compositionally diverse, but the focus should not be on ensuring that each division is, in itself, an accurate reflection of Piedmont habitat. Some divisions may be too small to contain a practically significant proportion of each habitat type, but steps should be taken that individual divisions are not dominated by only a few habitat types (see below).

- **Use evenness as a habitat diversity metric in individual divisions.** The Duke Forest can complement the implementation of habitat types by using a habitat diversity metric based on evenness for each of the divisions, which can serve as a proxy for biodiversity more generally. We recommend using the Berger-Parker index, which is extremely simple to calculate and relatively robust to small sample sizes, so Forest staff would not need to spend significant amounts of time collecting data.

    - The Berger-Parker index is calculated as

$$d = N_{max}/N$$

where N is the total number of parcels or acres in a division, N_{max} is the number of parcels or acres from the most frequently occurring habitat type, and d then represents the level of habitat dominance in a specific division.

  - Duke Forest could determine the habitat type of each parcel or acre via timber cruises, aerial imagery, et cetera. A high dominance score may encourage Forest staff to take actions that diversify habitat composition in that division through silvicultural prescriptions.

- **Designate non-harvestable land as habitat zones.** Where contiguous parcels are not managed for timber, Duke Forest should establish habitat zones that can be managed in accordance with established habitat thresholds and that can be altered as needed should a division become too uneven in its habitat composition. In instances where different taxa have contradictory responses to a management action, as in the case of reptiles and amphibians to mechanical thinning, these habitat zones may need to further specify a priority taxa.

Targeted wildlife management actions:

- **Monitor cross-taxa species richness.** Monitoring efforts should focus on species richness, both because the effects of management alternatives on species richness are poorly studied across all taxa, and moreover because Forest staff greatly prefer increases in biodiversity resulting from increased richness. This will also help Forest staff identify rare or other species of note for more targeted management. On harvestable land, wildlife surveys should be conducted both before and after harvest.

- **Emphasize management for amphibian biodiversity.** Because of the Piedmont's naturally high diversity of amphibians (Stein 2002), particularly salamanders (Wear and Greis 2013), we suggest that Duke Forest actively pursue management practices that promote either amphibian abundance or richness, or, where possible, both. Since amphibians tend to respond poorly to most management approaches, this would favor low impact management techniques where possible, and mitigating any tree removal with leaving downed coarse woody debris.

- **Birds, mammals, and reptiles respond well to higher density harvests.** Duke Forest should consider managing harvestable land for these three taxa and prioritizing amphibians, who respond poorly to all cutting practices, on non-harvestable land.

- **Develop research-based adaptive management strategies for each taxa.** The impact on mammals across each of the management categories is distinctly lacking. Duke Forest should implement adaptive management practices to fill in these gaps. Bird richness after harvest is also poorly studied, and should be the focus of ongoing investigation. Lower impact harvest approaches, such as shelterwood cuts and group selection cuts, should be assessed for their outcome on reptile and amphibian richness, while both taxa also require further study regarding the effects of fire on overall biodiversity.

7.2 Community-based monitoring

Potential benefits for Duke Forest from using community-based monitoring:
The potential for community-based monitoring within the Duke Forest is quite promising. Given the priorities and available resources expressed by the Duke Forest staff and the data obtained from the

interviews, we have developed several areas for the Duke Forest to build upon in order to establish a citizen science program.

- **Increased public engagement and education.** The most widely reported benefit during the interviews was the increase in public engagement and education when using community-based monitoring. Since the Duke Forest is a multi-use forest with a mission of education and outreach, this would be a great way to further educate the public on specific species within the Forest as well as how wildlife management occurs. Since clearcuttings often have a very negative connotation, it would be good to educate more people about the benefits of certain cuts for certain species as well as other practices (leaving standing deadwood, etc.) that are being implemented to mitigate negative effects of timber harvests.

- **Biodiversity Data.** The enhancement of baseline biodiversity was rated highly by the Forest (Section 6.2.3), and this could happen sooner with the higher amount of data that can be collected through citizen science than by a smaller group of professionals. Assuming that the Forest has a specific goal (see challenges below), using community-based monitoring can yield a much larger data set than any other method. Of note, however, is the time it takes for a program to gain enough volunteers to collect a large amount of data.

- **Expert contacts.** One of the greatest assets of conducting the interviews with the professional citizen science practitioners was developing contacts. Many individuals offered continuing support throughout the process of developing a citizen science monitoring platform in the Duke Forest. Several existing citizen science programs with platforms for various species monitoring schemes are present in proximity to the Duke Forest who offered their support.

- **Ability to detect problems early (trends over time).** The Duke Forest is an extremely valuable area due largely to the constant research in the same areas of forest over a long period of time. This value of the Forest could be expanded to more locations than the designated research plots to all accessible areas through the use of community-based monitoring. Furthermore, with the unknown effects of climate change, it is extremely valuable to have individuals on the ground constantly who know the land very well. Citizen science has shown this is one of its strengths because some volunteers can tell if there is a problem in the area immediately, such as a change in species presence or disease. One interview subject described citizen science as "an early alarm system".

- **Incorporating the use of community-based management or citizen science into a written management plan.** Since citizen science is such a recently emerging field in ecology, the Duke Forest has the potential to be an innovator by writing citizen science into their wildlife management plan. Several individuals whom we interviewed expressed how citizen science would fit well in an adaptive management plan, but how they have not seen it happen. The Duke Forest could help develop this approach and be on the forefront of officially incorporating citizen science into an adaptive management strategy.

Potential challenges for Duke Forest from using community-based monitoring:

- **Volunteer retention (matching volunteer interests with project goals).** To initially get volunteers and then to keep volunteers interested in participating, the Forest needs to make sure the public is interested in amphibians and reptiles. If there are not enough people in the area who have this interest, then a citizen science approach (given the stated priorities of the Duke Forest) will not be successful. The project must also continue to give the volunteers whatever it is about the program that keeps them interested over time, or volunteers will cease to participate. The Forest should obtain information regarding the reasons people are interested in being involved with the project. It was made evident during interviews that for a project to be sustained over time, the project must align with the volunteers' interests in both the data they are being asked to collect as well as providing opportunities for them to continue doing whatever their reasons they enjoy participating. For example, if people report participating because they enjoy the exercise and learning about science, then the program must continue to provide those services for the volunteers for them to return to collecting data. Though the Duke Forest did not rate aligning volunteer interests with project goals high, this must still occur for project success and may therefore be a challenge for the Forest. Some example questions could be:

1. Why do you enjoy visiting the Duke Forest?
2. What activities have you utilized the Duke Forest for in the past 6 months?
3. What are your top 3 reasons for participating in this program? Examples are: to be outside, get exercise, learn more about science, get involved with this community, make a difference for our environment, other (please state).
4. Do you have any suggestions on how we could make your participation in this program more enjoyable?
5. Other comments/recommendations?

- **Transparency.** Another important recommendation here is to share with the participants (through a social media group, email list serve or newsletter) what the Forest is doing with the data the volunteers collected as well as interesting trends or species in the data and why those trends or species are interesting. Here it is also important to note that something must be done with the data. If the data is not used for anything, the volunteers will likely feel there is no point to collecting the data and stop participating. The participants of the project can be the ones to continue analyzing the data as well, since there are many scales of community involvement for different types of citizen science.

- **Protocol Development.** One main finding was the importance of establishing a good protocol versus the very low amount of resources Duke Forest is willing to put towards both establishing a protocol and designing a program. This suggests that the Duke Forest should use an already existing program to avoid allocating many resources towards protocol and program design while ensuring a good quality program. This aligns with recommendations obtained through the interviews that the Duke Forest should tap into existing programs and applications as well as the satisfaction scorings from the Forest staff.

- **Perception of data quality.** Because the Duke Forest is part of an academic institution, there may be issues of professors or staff members not trusting data collected by citizens. As discussed in Lewandowski et al. (2015), data collected by citizens can be just as good as professional data collected and that the perception of data quality is often worse than the quality itself. It was also mentioned in some interviews that the scientists and managers involved in a project must all be willing to work with citizen science data and be trusting of the data being used. Finally, ensuring that some measure of effort is recorded with the data collection will improve the data quality and the perception of data quality.

- **Expressing exact goals of management plan.** Prior to launching any type of community-based monitoring scheme, clear and specific goals must be developed. If this is not done, the Forest will likely end up with a large amount of data that is not useful to their management objectives and then not used. This returns to volunteer retention issues because volunteers need to know the data collected is used for something of importance. The Duke Forest should utilize expert elicitation from citizen science practitioners who offered assistance during the interviews to ensure the goals of the management plan expressed would work with a citizen science platform. Other experts in wildlife management (many present at Duke) should also help to determine the goals of a management plan to make sure the stated objectives will be useful for the Duke Forest.

- **Data is publicly accessible.** The Forest may have issues using a platform on iNaturalist or other smartphone application because the data is publicly available to anyone. The locations of recorded species are accessible to anyone, and the Forest may not want this to be the case. However, there are ways to obscure exact locations on the iNaturalist app, which is often used when rare plant species are recorded in order to protect the species from public harm or theft. Another solution would be to create a new website specifically for the Duke Forest over which the Forest would have complete control of the data and therefore control how much to share and with whom to share it.

- **Spatial bias.** Because not all areas of the Forest are publicly accessible, the Forest will accrue data of species found along trails, roads and any other locations that are open to the public. Areas of the Forest where the public is not allowed or access is difficult will not be monitored nearly as often, if at all. To mitigate this effect, the Forest can train certain volunteers or elicit environmental student's help to access difficult areas. Another solution could be to organize events where groups of volunteers accompany staff members or scientists to all areas where species of concern may be located. The latter would also help to ensure data quality as well as build a stronger community with the volunteers.

Data Quality

- **Expert Involvement**. One important overlap of ensuring data quality from the literature and the resources of Duke Forest is the involvement of experts. Since Duke is an educational institution, the Forest already has many experts who could be consulted at no additional cost. Many experts specifically in the citizen science field have offered continued consultation and some have even offered partnerships.

- **Adequate Volunteer Training**. Training came up as both the number one reported challenge for a good program and as one of the top requirement to ensure data quality. Luckily, the Duke Forest has indicated that they are willing to provide a medium amount of training.

Taxa prioritization and protocol's to use:

- **Start Simple and Small.** As several people stated in the interviews, it is important to start small and simple. Therefore, the Duke Forest should begin monitoring for one taxa; we recommend herpetofauna. The Duke Forest staff weighted amphibians, reptiles and rare species equally, but as rare species are much more broad and may overlap with amphibians and reptiles, we recommend beginning with a focus on herpetofauna. Starting too large can result in obtaining too much data that is not useful.

- **Use a pre-existing protocol.** Based on the requirements for a successful citizen science program and the interests and priorities of the Duke Forest, we recommend to begin using a pre-existing citizen science program. This will align with the desire for a low amount of resources to go towards program design and protocol creation.

- **Begin a pilot project.** Once the previous initial start-up steps have been completed, a small pilot project should commence. This would ideally occur using volunteers who are already involved, and therefore familiar and invested with the Forest. Once a small group of volunteers has been established, working with these individuals and other experts in the citizen science field, can lead to any suggested changes to the program.

- **Existing programs across North Carolina.** The N.C. Wildlife Resources Commission currently has 2 programs which focus on herpetofauna. The 'HerpMapper Project' is a global program which tracks reptiles and amphibians and allows for partnerships (https://www.herpmapper.org/partners). Working specifically in North Carolina, NCWRC uses this data to monitor herpetofauna across the state. In the western part of North Carolina, 'Monitoring Projects for Amphibians' is a program specifically aimed at monitoring rare and endangered amphibians. The contact for this program (lori.williams@ncwildlife.org) could be a valuable person to discuss transferring aspects of this western North Carolina project to the Duke Forest. More locally, the Museum of Natural Science in Raleigh is participating in a program called 'Frogwatch USA' (http://naturalsciences.org/research-collections/citizen-science/current-projects). One potential issue with this project is the data is collected at night, when the Forest is not publicly accessible.

Appendix A: Data sources

Table A-1: Institutions that provided management plans.

Name	Date Published	Industry	Region
Alex Fraser Research Forest	2007	Academic	WMW
Austin Carry Forest	2016	Academic	SSE
Blodgett Forest	1999	Academic	WMW
Blodgett Forest Research Station	2012	Academic	WMW
Centiennial Forest	2002	Academic	WMW
Clemson Experimental Forest	2013	Academic	SSE
Cloquet Forest	2015	Academic	WMW
Craig Mountain WMA	1998	State	WMW
Duke Forest	2015	Academic	SSE
Griffith Park	2008	Municipal	WMW
Guana River	2015	State	SSE
Harvard Forest	2008	Academic	NNE
Herky Huffman/Bull Creek	2011	State	SSE
High Tor WMA	2016	State	NNE
Holt Forest	1983	Academic	NNE
Massabesic Experimental Forest	2006	Federal	NNE
McDonald-Dunn Forest	2005	University	WMW
Mountain Longeaf NWR	2005	Federal	SSE
Olympic Experimental State Forest	2016	State	WMW
Pack Forest	2009	Academic	WMW
Penobscott Experimental Forest	2009	Academic	NNE
Petawawa Research Forest	2015	Federal	NNE
South Mather Wetlands	2013	Municipal	WMW
St. Marks NWR	2013	Federal	SSE
Swanton Pacific Ranch	2015	Academic	WMW
WVU Forest*	[unavailable]	Academic	SSE
Yale School Forest	2006	Academic	NNE

Table A-2: Meta-analyses used in determining effect sizes.

Greene, Rachel E., et al. "A meta-analysis of biodiversity responses to management of southeastern pine forests—opportunities for open pine conservation." *Forest Ecology and Management* 360 (2016): 30-39.
Kalies, E. L., C. L. Chambers, and W. W. Covington. "Wildlife responses to thinning and burning treatments in southwestern conifer forests: a meta-analysis." *Forest Ecology and Management* 259.3 (2010): 333-342.
Riffell, Sam, et al. "Biofuel harvests, coarse woody debris, and biodiversity–a meta-analysis." *Forest Ecology and Management* 261.4 (2011): 878-887.
Thom, Dominik, and Rupert Seidl. "Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests." *Biological Reviews* (2015).
Vanderwel, Mark C., Jay R. Malcolm, and Stephen C. Mills. "A Meta-Analysis of Bird Responses to Uniform Partial Harvesting across North America." *Conservation Biology* 21.5 (2007): 1230-1240.

Verschuyl, Jake, et al. "Biodiversity response to intensive biomass production from forest thinning in North American forests–a meta-analysis." *Forest Ecology and Management* 261.2 (2011): 221-232.

Zwolak, Rafał. "A meta-analysis of the effects of wildfire, clearcutting, and partial harvest on the abundance of North American small mammals." *Forest Ecology and Management* 258.5 (2009): 539-545.

Appendix B: Systematic review protocols

Systematic Review: What are the common wildlife management goals and techniques utilized by multiuse forests in the Southeastern United States?

Background

The Duke Forest comprises some 7,000 acres of mixed use land dedicated to education and research, resource management, and recreation (DFMP 2015). Under the aegis of resource management, Duke Forest manages wildlife with the express aim of the "encouragement and maintenance of a diversity of wildlife species representative of the many animal communities native to the Piedmont of North Carolina" (DFMP 2015). The current management plan, last updated in 2015, emphasizes as wildlife priorities its amphibian populations, wild turkey populations, and the fisheries and benthic communities of the New Hope Creek and Eno River (DFMP 2015).

Wildlife management activities generally seek to increase habitat diversity at both the landscape and stand level, but this is mostly due to lacking comprehensive species lists and related population estimates (DFMP 2015). Directors of the Forest, presently lacking a habitat guide specific to the Piedmont of North Carolina, use Evans' (1974) description of Missouri forest habitat to guide decisions (DFMP 2015). As such, habitat is managed to emphasize mast-producing species, mixed hardwood and mature pine, and old growth forest. These compositional goals are used in conjunction with the Shannon-Weaver diversity index to maximize potential habitat diversity within the confines of Duke Forest (Dickman 1968, DFMP 2015).

Managing habitat in the Duke Forest is predominantly a process of managing stand size and open fields. In managing stands, the Forest seeks to ensure that at least some stands are large enough to provide habitat for interior specialists, while also maintaining existing edge habitat. Stands below one square-acre are to be merged with larger stands, while expansive stands may have areas within cleared to create additional edge territory. To maintain open fields, the existing management plan calls for periodic mowing to encourage both new herbaceous growth as well as colonization by arthropods (DFMP 2015). Furthermore, the Duke Forest has, in accordance with the North Carolina Wildlife Resource Commission (2002, 2009), established Riparian Management Zones around permanent and ephemeral water bodies to provide increased habitat and better facilitate movement of many native species through the landscape (DFMP 2015).

Objectives

The aim of this review is to create a comprehensive list of wildlife management practices and associated goals currently utilized by multiuse forests, especially research forests in the Southeastern United States. These practices will be assessed for their relevance in inclusion in an updated wildlife management plan for the Duke Forest.

Primary and Secondary Questions

1. What are the common wildlife management goals and associated practices of multiuse forests in the Southeastern United States?
    a. What metric of biodiversity is being used in other multiuse forests?

b. What kind of species are being targeted by peer institutions?
c. What management techniques exist for the variety of taxa within Duke Forest?

Searches

An initial scoping revealed that using traditional search key words was ineffective in locating institutions with similar multi-use forest. Efforts were shifted instead to locating schools with forestry programs and associated forests and contacting these institutions directly. We will also leverage our client's connections with the Eastern Research Forest Managers informal network to obtain either formal management plans or collected practices currently in use at peer institutions in Eastern North America. Finally, we will contact neighboring state fish and wildlife management agencies to solicit any wildlife management plans and protocols they may be using.

Study inclusion criteria

First, we included articles examining forests used for any similar purposes; forests must be used for research, timber, and/or recreation. Relevant habitats will reflect the proposed habitat composition of the Duke Forest [see Table 2.F-2, DFMP 2015]. We focused on articles with relevant wildlife priorities, and outcomes reflecting the objectives as outlined in the Mission Statement of the DFMP.

We assessed studies first by title, then by abstract, and finally the full text, for relevancy according to the criteria listed in Table 1. The review team consisted of two people assessing each hit independently, with discrepancies being decided by a third reader. We then conducted a kappa analysis to determine the specificity and sensitivity of each readers study inclusion criteria (CEE 2013).

Data extraction strategy, synthesis, and presentation

In accordance with best practice guidelines, data extraction was completed by two members of the Review Team (CEE 2013). All data extracted from included studies was recorded in a data collection spreadsheet that included variables related to institution, use, habitat, taxa, etc.

Data analysis consisted of frequencies for each practice, and was cross-tabulated for each target taxa and/or target habitat. Simple histograms were constructed to display those tabulations visually.

Systematic Review: What are the best practices for managing wildlife in multiuse forests in the Southeastern United States?

Background

The Duke Forest comprises some 7,000 acres of mixed use land dedicated to education and research, resource management, and recreation (DFMP 2015). Under the aegis of resource management, Duke Forest manages wildlife with the express aim of the "encouragement and maintenance of a diversity of wildlife species representative of the many animal communities native to the Piedmont of North Carolina" (DFMP 2015). The current management plan, last updated in 2015, emphasizes as wildlife priorities its amphibian populations, wild turkey populations, and the fisheries and benthic communities of the New Hope Creek and Eno River (DFMP 2015).

Wildlife management activities generally seek to increase habitat diversity at both the landscape and stand level. This is accomplished primarily through silvicultural prescriptions and timber management practices that seek to create a wide variety of habitat within the Forest's bounds. The current plan focuses on increasing non-forested land coverage, continuing to harvest mature pines and promote the regeneration of younger pine stands, and promoting and protecting lowland hardwood communities (DFMP 2015). Directors of the Forest, presently lacking a habitat guide specific to the Piedmont of North Carolina, use Evans' (1974) description of Missouri forest habitat to guide decisions (DFMP 2015).

Managing habitat in the Duke Forest is predominantly a process of managing stand size and open fields. These general habitat units are managed so that coverage is comprised of 40% mast-producing species, 30% mature pine-mixed hardwood forest, 20% permanent open field, and the remaining 10% old growth forest (Evans 1974). Habitat composition goals are used in conjunction with the Shannon-Weaver diversity index to maximize potential habitat diversity within the confines of Duke Forest (Dickman 1968, DFMP 2015).

Stands are managed to ensure that at least some are large enough to provide habitat for interior specialists, while also maintaining existing edge habitat. Stands below one square-acre are to be merged with larger stands, while expansive stands may have areas within cleared to create additional edge territory. Forest clearings, which have been identified as especially important for species native to the Southeastern United States (Menzel *et al.* 1999, Dickson 1983) are periodically mowed to encourage both new herbaceous growth as well as colonization by arthropods (DFMP 2015). Clearings created for powerline right-of-ways create natural corridors and enable the rise of early seral vegetation, a preferred habitat for many Duke Forest species (Litvaitis 2001, Anderson 1991). Finally, the Duke Forest has, in accordance with the North Carolina Wildlife Resource Commission (2002, 2009), established Riparian Management Zones around permanent and ephemeral water bodies to provide increased habitat and better facilitate movement of many native species through the landscape (DFMP 2015).

Objectives

The aim of this review is to compile a list of best wildlife management practices for use in the Southeastern United States. **Practices are not being assessed for their feasibility, but rather their efficacy in meeting target goals like increased biodiversity, and will come from peer reviewed studies.**

Primary and Secondary Questions

1. What are the best practices to promote and maintain biodiversity in multiuse forests in the Southeastern United States?
    a. What is the most useful metric of biodiversity?
    b. What practices best promote diversity within relevant taxa or habitat?
    c. How is each practice evaluated for efficacy?
    d. How effective is each practice?

Searches

A literature search was conducted using combinations of words from each of the columns listed in Table 2. Searches were conducted via combining each term from Table 2 in the format "Management technique" AND "Wildlife taxa" AND "Geographic region OR Habitat." The following databases were queried: Web of Science, Scopus, CAB Abstracts, BIOSIS, Environment Complete, Zoological Record (M. Peper, personal communication, September 15, 2016).

Study inclusion criteria

Articles were included based on the criteria listed in Table 3. First, we included articles examining forests used for similar purposes as the Duke Forest, i.e. research, timber, and/or recreation. Relevant habitats reflect broadly the habitats found in the Duke Forest. We focused on articles with relevant wildlife priorities, and outcomes reflecting the objectives as outlined in the Mission Statement of the DFMP.

We assessed studies first by title, then by abstract, and finally the full text, for relevancy according to the criteria listed in Table 3. The review team consisted of two people assessing each hit independently, with discrepancies decided by a third reader. We then conducted a kappa analysis to determine the sensitivity and specificity of each reader's inclusion criteria (CEE 2013).

Management plan quality assessment

Following Pullin and Knight (2001), we analyzed our resulting list of studies for the elements from Table 4. Studies were weighted depending on the category they fell into, with category I weighted the heaviest.

Data extraction strategy

In accordance with best practice guidelines, data extraction was completed by two members of the Review Team (CEE 2013). All data extracted from included studies were recorded in a data collection spreadsheet that included variables related to institution, use, habitat, taxa, etc., as well as study design and status of publication.

Data synthesis and presentation

Data extracted from the reviewed literature was analyzed to assess the effect size of each practice. Following Hedges, *et al.,* (1999), we calculated the effect size as ln(experimental mean/control mean), as this formulation minimizes bias and has a relatively normal sampling distribution. Since response ratios cannot be determined when either mean value is equal to zero, such values were replaced with a value equal to 0.001, as this has the smallest impact on overall effect size (Kalies *et al.* 2010). Effect sizes were weighted by the inverse sample variance (Kalies *et al.* 2010) or, if standard deviations were not reported, by the number of replicates in the study (Johnson 2002). Results were displayed as mean effect sizes with associated confidence intervals per taxa, per habitat, and/or per management practice, as needed.

Systematic Review: What are the common practices recommended or used to ensure adequate data quality for papers utilizing data obtained from volunteer citizens?

To assess what scientists were doing to ensure quality of citizen science data, we conducted a second systematic review. Using one term from each column of Table 8, two questions were answered:

1. What methods are scientists using to ensure high quality citizen science data for long term species monitoring?
2. How are various social and personal characteristics affecting quality of data collected by volunteers?

The final cull included articles published 2014 and later, and met the following other criteria; excluded any studies on marine, astrology, disease, medical studies, policy/governing, education and air quality; no species distribution modeling; not a peer reviewed article.

Appendix C: Decision tables

Weights	
Abundance	0.30
Richness	0.70

Satisfaction	Ratio	Score	Satisfaction
+++	5000000	50000000	1.00
++	2500000	25000000	0.50
+	1500000	15000000	0.30
0	1000000	10000000	0.20
-	500000	5000000	0.10
- -	100000	1000000	0.02
- - -	1	10	0.00

Birds

	High Intensity Fire	Low/Mid Intensity Fire	Fire + Thinning	Fire + Herbicide	
Abundance	1.00	1.00	0.50	0.30	
Richness		0.00		0.30	
Score	0.30	0.30	0.15	0.30	
	Selection Harvest	Group Harvest	Shelterwood	Clearcut	
Abundance	1.00		1.00	1.00	
Richness					
Score	0.30	0.00	0.30	0.30	
	DCWD Removed	DCWD Added	Snags Removed	Snags Added	Both Removed
Abundance	0.10		0.02	0.10	0.10
Richness	0.10		0.10	0.10	0.02
Score	0.10	0.00	0.08	0.10	0.04

Mammals

	High Intensity Fire	Low/Mid Intensity Fire	Fire + Thinning	Fire + Herbicide	
Abundance	0.50	0.20	0.50	0.30	
Richness		0.10		0.20	
Score	0.15	0.13	0.15	0.23	
	Selection Harvest	Group Harvest	Shelterwood	Clearcut	
Abundance	0.10		0.50	0.50	
Richness					
Score	0.03	0.00	0.15	0.15	
	DCWD Removed	DCWD Added	Snags Removed	Snags Added	Both Removed
Abundance					
Richness	0.30	0.10		0.30	0.10
Score	0.21	0.07	0.00	0.21	0.07

Reptiles

	High Intensity Fire	Low/Mid Intensity Fire	Fire + Thinning	Fire + Herbicide	
Abundance		0.10		0.10	
Richness		0.10		0.10	
Score	0.00	0.10	0.00	0.10	
	Selection Harvest	Group Harvest	Shelterwood	Clearcut	
Abundance	0.02	0.50	1.00	0.30	
Richness	0.30			0.50	
Score	0.22	0.15	0.30	0.44	
	DCWD Removed	DCWD Added	Snags Removed	Snags Added	Both Removed
Abundance	0.10	0.10		0.30	0.20
Richness	0.20	0.20		0.30	0.30
Score	0.17	0.17	0.00	0.30	0.27

Amphibians

	High Intensity Fire	Low/Mid Intensity Fire	Fire + Thinning	Fire + Herbicide	
Abundance	1.00	0.10		0.10	
Richness		0.10		0.10	
Score	0.30	0.10	0.00	0.10	
	Selection Harvest	Group Harvest	Shelterwood	Clearcut	
Abundance	0.02	0.00	0.10	0.00	
Richness	0.10			0.30	
Score	0.08	0.00	0.03	0.21	
	DCWD Removed	DCWD Added	Snags Removed	Snags Added	Both Removed
Abundance	0.10	0.30		0.10	0.10
Richness	0.10	0.20		0.20	0.20
Score	0.10	0.23	0.00	0.17	0.17

Appendix D: Interview IRB

In order to be eligible to conduct interviews, an approval is needed from an Institutional Review Board (IRB) to ensure no harm will be done to participants and allow for informed consent from participants. For our project purposes, a full IRB was not required. Instead, we filed for an exemption from IRB approval, which was accepted:

Research Description:

1. Research Design

Citizen science is a rapidly emerging tool that appears to be utilized often without being officially incorporated in specific wildlife management plans. From initial research into this topic, we believe that speaking with practitioners on the cutting edge of actively using citizen science in adaptive management approaches is the best way to determine if citizen science would be a good tool to use in the wildlife management plan for Duke Forest.

Since the aim of this study is to determine the best way to write in citizen science to the revised management plan for Duke Forest, we believe conducting semi-structured interviews with experts across the country who are currently using citizen science to manage habitats will be the most effective way to discern how to officially write in a citizen science component to the plan. We anticipate arranging phone interviews via email, which will take between 30 and 45 minutes, depending how in depth the participant wishes to go. We will include information regarding geographic locations and possibly forest names.

2. Subject Selection

Subjects will be professionals across the country who are actively engaged in forest management with citizen science techniques. The list of people found so far are from simple word of mouth and attending a citizen science symposium in the spring of 2016 at Duke University. We are unsure exactly how many subjects there will be, as we plan on using snowball sampling to expand my selection throughout the process. We hope to recruit approximately 20 different subjects to speak with.

3.Informed Consent

Thank you for agreeing to speak with me. This study is designed to research how citizen science could be best included in a formal wildlife management plan. The data used will be to help determine what the best practice will be for Duke Forest and the new adaptive wildlife management plan. Therefore, location and species present will need to be recorded and considered and this information will not be confidential. However, all personal information will remain confidential unless otherwise discussed and consent is received. The information from interviews will be retained for 5 years after publication.

This interview will take between 30 and 45 minutes, depending on the depth you wish to go into with your answers. The more in depth we go, the greater benefit this study will potentially provide to the future of citizen science within adaptive wildlife management plans. Participation is completely voluntary and you may stop the interview at any time if requested. If you choose to end the survey early, we will ask you if we can retain any data already obtained. If you have any further questions, please contact Renee Kramer [renee.kramer@duke.edu], Hannah Palmer-Dwore [hannah.palmer.dwore@duke.edu] or Peter Satin [peter.satin@duke.edu].

Interview Questions

These are the main questions we will be shaping the conversation around. Other sub-topics may be addressed throughout the conversation.

4. How do you currently use citizen science within the wildlife management plan for your organization?
5. What is the aim of your management plan? (i.e. endangered species conservation, retaining high biodiversity, etc.)
6. What species do you use citizen science to manage?
7. When did you start using citizen science and why?
11. What do you see as the advantages of incorporating citizen science as compared to other techniques? In your opinion, how valuable is citizen science relative to other types of information on a scale of 1-5, with 5 being very valuable.
12. What has not worked well for you when using citizen science (any downsides)?
13. Is your citizen science approach written into a formal management plan?
14. Which apps (if any) do you use and how does this data integrate into your management of target species?
15. Do you have any suggestions about incorporating citizen science into an adaptive wildlife management plan?
16. Is there anyone else you think would be of value for me to speak to about using citizen science to manage for wildlife?

Email recruitment notice.

Dear ______,
My name is Renee Kramer (or whoever send the email). I am a masters' student at the Nicholas School of the Environment at Duke University and am currently working on my masters' project. For this project, I will be working with two other students [Hannah and Peter] to rewrite the wildlife management plan for Duke Forest. In order to create an adaptive wildlife management plan, we are planning to integrate citizen science data collection into the plan. Since citizen science is an emerging field, we are hoping to gather ideas and information from current forest managers (like yourself) who are actively
using citizen science data to make management decisions. Please let me know if you would be willing to discuss your citizen science practices with me over the phone in the next week or so. The interview would take 30-45 minutes.
Thank you for your time,

Renee Kramer (Or whoever sent the email)

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