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RESEARCH ARTICLE

Understanding the key characteristics and challenges of pine barrens restoration: insights from a Delphi survey of forest land managers and researchers

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Pine barrens are open-canopy ecological communities once prevalent on sandy soils across the northern Great Lakes Region of the United States and Canada, though fire suppression and plantation forestry have now reduced them to a few isolated areas. Efforts to restore pine barrens are underway on some public lands, but lack of knowledge on the social and ecological issues and challenges that affect these projects impedes fuller progress. As a precursor to designing a public preference survey for pine barrens restoration, we sought input from those with expert knowledge about pine barrens. Using a three-round modified Delphi survey, forest land managers and researchers identified the key characteristics of pine barrens and important current and future management challenges. Key characteristics were related to fire, landscape structure, plant and animal species, soils, and social themes. Current and future challenges were related to landscape, invasive species, social, economic, climate change, and science themes. Four social issues (education, fire acceptance, fire risk, aesthetics) were rated among the top current challenges but none of them maintained prominence as future challenges. Potential explanations for this shift are that the experts felt these social concerns would be resolved in time or that other issues, such as development pressures and budgets for carrying out restoration, would become greater future challenges. Our approach can be used by managers and researchers to better understand the ecosystems they seek to restore and to communicate with public stakeholders about restoration efforts.

Key words: barrens and savannas, ecological restoration, expert knowledge, landscape characteristics, management challenges, northern Great Lakes region, open-canopy ecological communities, public perceptions

Implications for Practice

- Public unfamiliarity with pine barrens and concerns about their management could constrain restoration efforts.
- The open, fire-dependent nature of pine barrens are key characteristics that pose challenges to their public acceptance.
- Other characteristics such as native species diversity, abundant wildlife, and prevalence of berry-producing shrubs may be used as "selling points" to attract stakeholders and build awareness.
- Current top-ranked social challenges of pine barrens restoration may decline in priority as managers anticipate greater future challenges such as landscape fragmentation and declining budgets.
- The Delphi technique has value for understanding ecosystem restoration priorities.

Introduction

A pine barrens is a fire-dependent savanna community with an open canopy of pine growing scattered or in clumps over a varied understory of grasses, forbs, and shrubs (Curtis 1959; Quigley et al. 2019). Once prevalent on sandy glacial outwash areas of the northern Great Lakes Region of the United States and Canada, fire suppression, plantation forestry, and agricultural conversion have reduced their presence to a few isolated sites, mostly on public lands. Because of their rarity as an ecological community and the habitat they provide for several plant and animal species of high conservation interest, land managers

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are working to restore pine barrens across their historic range (Radeloff et al. 2000).

The State of Wisconsin (United States) is a historical center of jack (*Pinus banksiana)* and red pine (*Pinus resinosa*) barrens in the northern Great Lakes Region (Pregitzer & Saunders 1999; USDA Forest Service 2004). To contribute to regional restoration efforts, in 2014 forest managers on the Chequamegon-Nicolet National Forest began work with ecologists at the U.S. Department of Agriculture-Forest Service's Northern Research Station to restore pine barrens and associated dry forest communities as part of the Lakewood Southeast Project. As social scientists, we were asked to join this project to help understand stakeholder perceptions of the restoration effort and how its implementation could increase public acceptance. To develop a landscape preference survey, we first sought input from forest land managers and researchers with expertise in pine barrens restoration to identify the key characteristics of this landscape and the most important current and future management challenges. In this article, we characterize pine barrens restoration in a social-ecological context, describe the results of our expert-based Delphi inquiry, and discuss the social implications for restoring pine barrens on public lands.

Social-Ecological Perspectives on Pine Barrens

While pine and savanna ecosystems are represented on nearly every continent, pine barrens are almost exclusively North American (NatureServe n.d.). The ecological vegetation classification system used by the NatureServe Network includes pine barrens within 5 groups, 6 alliances, and 41 associations, most of which are ranked globally vulnerable (G-3), imperiled (G-2), or critically imperiled (G-1) (NatureServe n.d.; Faber-Langendoen et al. 2016). The jack and red pine barrens of the northern Great Lakes Region were historically represented in the northern portions of Minnesota, Wisconsin, Michigan, and New York in the United States and southeast Manitoba and eastern Ontario in Canada (Pregitzer & Saunders 1999). They share similar physical characteristics with pitch pine (*Pinus rigida*) barrens of the northeastern United States, with dry soils and frequent fires resulting in a sparse, pine-dominated canopy (Anderson et al. 1999).

These ecosystems also share similar social and cultural histories. North American Indigenous peoples long used fire to maintain the open character of pine barrens as a preferred landscape condition for wildlife habitat, medicines, materials for human subsistence (Cronon 1983; Kimmerer & Lake 2001), and food—particularly for the production of blueberries (*Vaccinium angustifolium* and *Vaccinium myrtilloides*) (Murphy 1931). While seventeenth century European colonists likely also appreciated berry-picking in the pitch pine barrens of the northeastern United States, fire was not seen as a management tool and "productivity" was viewed in terms of agriculture and forestry. For these purposes, the openness of pine barrens was perceived as literally barren and they were considered places of last resort for agricultural settlement (Wacker 1979).

Early forestry assessments in northern Wisconsin also expressed a dim view of pine barrens in contrast with the state's famed "pinery" surrounding them, calling them "monotonous brushwoods" (Roth 1898, 10) "almost worthless" (Fletcher 1853, cited in Lampereur 2013, p. 10) for timber harvesting. Once the northern forest was liquidated, Depression-era work programs in the 1930s, such as the U.S. federal government Civilian Conservation Corps, restocked the depleted pinery with plantation-style pine monocultures, including areas that were historically open pine barrens (Lampereur 2013; Fig. 1). Combined with an effective program of fire suppression, the end result has been a near-total erasure of pine barrens in the state, from an estimated original extent of 930,000 ha to around 4,000 ha in the 2010s (Vora 1993; Lampereur 2013).

Early concerns for the loss of this landscape from Wisconsin and elsewhere were driven in large part by the declining population of grassland game birds such as the greater prairie chicken (*Tympanuchus cupido*) and sharp-tail grouse (*Tympanuchus phasianellus*) (Curtis 1959). Fire suppression was recognized as a contributing factor in this decline, and one of the first efforts in restorative management of pine barrens was a 1947 prescribed burn to restore grouse habitat on state-owned land in northwestern Wisconsin (Vogl 1970). Nearby federal land at Moquah had been set aside in 1932 to protect the unique ecology of the pine barrens landscape, but its designation as a Research Natural Area emphasized the study of vegetation succession and for decades no management was allowed except for fire *prevention* (Ribic et al. 2016). Increased attention to endangered species expanded the use of burning as a management tool for pine barrens, including efforts in the 1980s to increase habitat for the federally endangered Kirtland's warbler (*Dendroica kirtlandii*) in the Upper Peninsula of Michigan (Corace 2001). With the advent of ecosystem management in the 1990s, experiments to restore pine barrens included burning and a broader range of tree cutting and planting treatments (Vora 1993). As of 2020, the Lakewood Southeast Project and other efforts at county, state, and federal levels continue to build on this restoration legacy.

Because of its rarity as a landscape type, few empirical studies have examined public perceptions and uses of pine barrens. A social analysis of the Pine Barrens region of northwest Wisconsin (Schewe et al. 2012) only mentions its ecological character in passing. Rather, in this and other scholarly treatments from the social sciences (e.g. Gobster & Rickenbach 2004) and humanities (e.g. Shapiro 2013), the dominant public perception of the "Northwoods" landscape of northern Wisconsin, Minnesota, and Michigan is one of a mature, unbroken forest that forms the backdrop for outdoor recreation and seasonal/retirement homes. In a pilot effort that led to our present study, focus group participants ($n = 12$) who owned land near the Lakewood Southeast Project expressed their preferences for five images of forest landscapes from the region that varied on a canopy gradient from very closed to very open (Floress et al. 2018). While there was some support for a scene showing a semi-open canopy, consistent with dominant perceptions of Northwoods scenery, participants most preferred the landscape with the densest canopy and least preferred the most open photos of pine barrens. Other studies of forest landscape perceptions generally agree with this idea, where closed forest conditions with mature trees

Figure 1. Historical photos of pine barrens around the Lakewood Southeast Project area. Upper left: Open landscape with single red pines thermally pruned from a moderate-intensity fire. Upper right: Clumps of mature and young jack pine. Lower left: Civilian Conservation Corps (CCC) breaking the sod for tree planting. Lower right: CCC crew tree planting. All photos were taken in 1936 by U.S. Department of Agriculture except upper left, 1928 by FT Thwaites, Wisconsin Geological and Natural History Survey.

and an open understory are highly preferred, and where large openings created by clearcutting are looked upon negatively (Ribe 1989). Broader studies of globally represented biome preferences also show that closed and semi-open forests are preferred over open landscapes such as grasslands and deserts (e.g. Han 2007). There can be important cultural differences, however. For example, Indigenous peoples have expressed generally positive perceptions of fire-adapted ecosystems and the resulting ecological and cultural attributes (Raish et al. 2007).

Expert Insights and the Delphi Technique

To identify the key characteristics and challenges of pine barrens restoration, we sought the expertise of forest land managers and researchers familiar with restoring savanna and barrens ecosystems. Expert opinion can be useful for identifying and developing consensus on complex issues for which there is a limited or conflicting knowledge base (Delbecq et al. 1975). Among the various methods for structuring expert input, the Delphi technique is well-established (Linstone & Turoff 1975; Hsu & Sandford 2007) and has received increased use to study environmental management issues (Cole et al. 2013).

The Delphi is an iterative process whereby expert participants anonymously share, refine, and prioritize issues through recurring rounds of participation. Typically, the number of rounds varies from between three to five (Delbecq et al. 1975). In the first round, participants respond to open-ended questions and generate a list of ideas and responses. These responses are then organized and returned to the participants for a second round of rating and/or ranking. In a third round, participants are presented with their ratings as well as the group's mean ratings with an opportunity to revise their ratings and explain any changes. Further rounds work to refine ideas and solidify consensus if necessary.

The anonymity, controlled feedback, and iterations make the Delphi an appealing way to attain a full range of ideas and reduce bias and noise (Dalkey & Rourke 1972). Compared with face-to-face approaches such as the nominal group technique, experts often prefer the Delphi because of its efficiency and perceived impartiality (Waldron et al. 2016). Its flexibility also allows it to be used to generate hypotheses, research agendas,

and other types of information to move issues forward into an action arena (Hernández-Morcillo et al. 2017). Some Delphi applications relevant to restoration ecology include identifying key aesthetic attributes of coastal ecosystems (Urbis et al. 2019), defining ecological criteria for setting forest restoration priorities (Orsi et al. 2011), and understanding the values that drive nature-based recreation management (von Ruschkowski et al. 2013).

Methods

Study Area

The 15,000 ha Lakewood Southeast Project is located in the Chequamegon-Nicolet National Forest in northeastern Wisconsin (Fig. 2). The project area falls within the Northeast Sands ecoregion, one of two lobes of sandy glacial outwash that intercede the broader, socially defined region of dense forest cover known as Wisconsin's Northwoods. These sandy areas historically had the greatest concentration of jack and red pine barrens in the state, and the project contributes to other major pine barrens restoration efforts in the state, notably Spread Eagle Barrens in the Northeast Sands and Moquah Barrens in the Northwest Sands (Sturtevant et al. 2016). Restoration treatments within the project area include clearcutting and thinning of trees to create a gradient of open conditions and diversify stand age structure; chipping and removal of slash to hasten understory growth; and prescribed burning to restore historic fire regimes (Fig. 3).

Participant Sample

Our population of experts included forest land managers and researchers with knowledge and experience of pine barrens communities in the northern Great Lakes Region. We developed an initial list of potential participants from authors of research reports and articles and then worked with members of the Lakewood Southeast Project to identify practitioners from federal, state, and non-profit sectors.

A list of 49 individuals resulted, 18 of whom agreed to participate in round 1, 11 who continued to round 2, and 10 who participated in all three Delphi rounds. The lowered participation rate between rounds is not unusual (Hsu & Sandford 2007; Wolf & Kruger 2009) and the retention between rounds 2 and 3 is indicative of an engaged set of experts. The panel for round 1 included forestry researchers (39%), forestry managers (33%), and others (27%); with experience at governmental (51%;

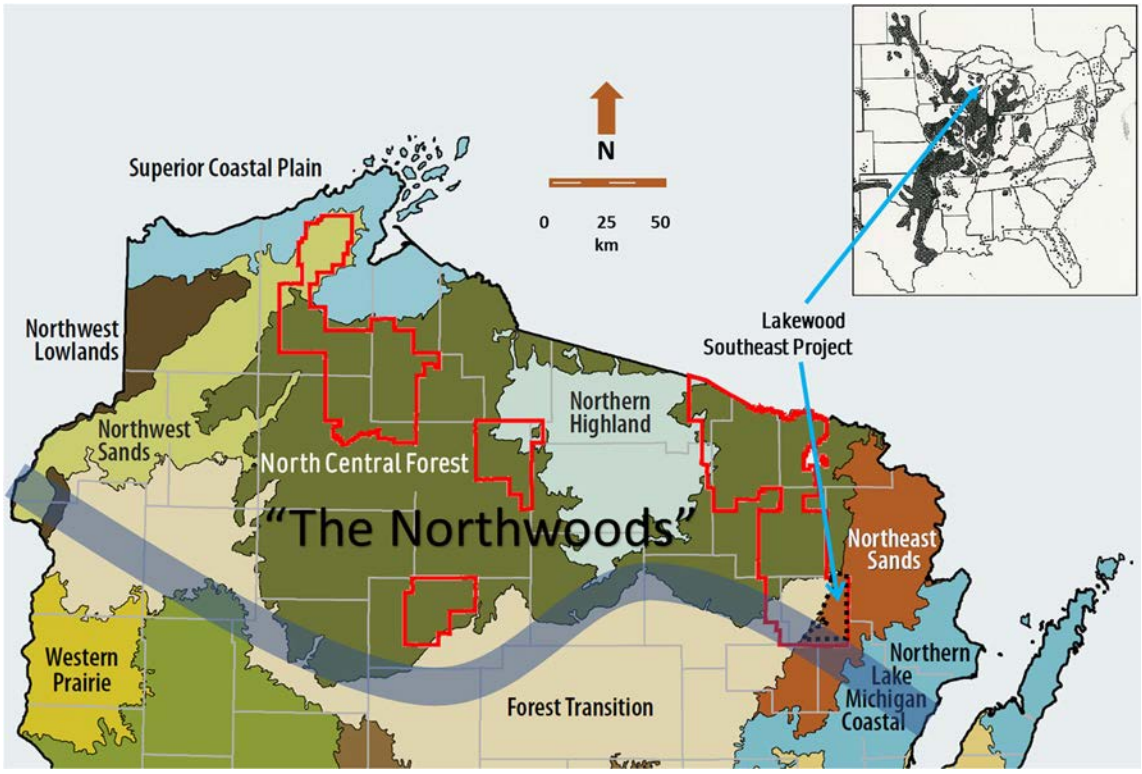

Figure 2. The Lakewood Southeast Project area (hatched boundary) is located within the Chequamegon-Nicolet National Forest (red boundary) in northeastern Wisconsin. The project area falls within the Northeast Sands ecoregion, which along with the Northwest Sands (far left) are sandy areas of glacial outwash that contain the greatest concentration of remnant pine barrens in the state. The region north of the ecological tension zone (broad line) is often referred to as Wisconsin's Northwoods, and while the sands ecoregions were historically more open in character, most people today consider the dense forest cover of the Northwoods as natural. Inset map shows the historic distribution of pine barrens, oak barrens, and oak savanna ecosystems in eastern North America (base map credits: Wisconsin Department of Natural Resources 2015, inset map credit, USDA Forest Service 2004).

Figure 3. Photos of Lakewood Southeast Project restoration treatments, Chequamegon-Nicolet National Forest. Top panorama: Pre-treatment, 2017. Bottom panorama: Post-treatment, 2018. Bottom left: Post-treatment removals, 2017. Bottom right: Post-treatment burning, 2019. USDA Forest Service photos.

federal, state), academic (22%), and non-profit (21%) sectors; who averaged 20 years of professional experience.

Delphi Process

To structure experts' input, we employed a three-round modified Delphi technique. Our modifications were using three rounds and electronic access, which are increasingly common (Wolf & Kruger 2009; Cole et al. 2013). The process began in November 2017 with participants responding to open-ended questions. Two rounds followed in January and March 2018, in which participants rated the importance of statements identified in round 1. The Delphi was administered using Qualtrics software and upon accepting the invitation, participants were emailed a link to an online questionnaire for each round. Draft versions of the first- and second-round questionnaires were pretested by a few forestry professionals to assess wording clarity and completion time.

The first-round questionnaire briefly introduced the study topic (pine barrens in the northern Great Lakes Region) and purpose (to understand key characteristics, management challenges, and public perceptions). A warm-up question asked participants to describe what a healthy pine barrens looks like to them. This next question on the key characteristics of pine barrens asked participants to list all the things they felt are important, with a prompt mentioning various ways in which people may think about pine barrens' characteristics:

> *…stand versus landscape level characteristics; biophysical /forest mensuration characteristics; ecological processes; management/restoration practices; functions and uses; how barrens are perceived, experienced, and used. As you list each characteristic, please feel free to elaborate on the specific nature of that characteristic and/or why you think it's important.*

Separate questions on present and future pine barrens management challenges followed, again asking respondents to list all the challenges they thought important. The first-round questionnaire ended with a few demographic questions to characterize the sample, and questionnaires for all three rounds included space to add any additional comments or attach files that would aid in understanding the issues.

The second-round questionnaire provided participants with a list of brief statements describing 19 key characteristics, 20 current challenges, and 26 future challenges derived from content analysis of round 1 open-ended responses (see Data Analysis section below). For each statement, participants were first asked to rate its importance on a sliding scale from 1 = very unimportant to 9 = very important. Two spaces were provided to add important characteristics or challenges not in the list of statements. To further discriminate among the top concerns, respondents were then asked to rank their five most important characteristics or challenges from 1 = most important to 5 = least important.

In the third round, participants were given the same statement lists as round 2, but this time each statement was followed by the mean group importance rating from round 2 along with their own second-round rating. Participants considered their own rating in light of the group rating and made adjustments if desired. The statements added by individuals from round 2 were also included and rated for importance by all third-round participants.

Data Analysis

Studies employing Delphi and related techniques often must rely upon small respondent samples when the pool of experts available to address a narrow, highly specialized subject material such as ours is limited (Diamond et al. 2014). Our analysis combines qualitative and quantitative aspects, though with the constraints of our sample, our presentation of the data focuses on the emergent themes from round 1 and general pattern of importance ratings and rankings in rounds 2 and 3.

Open-ended responses from round 1 were independently coded by two of the investigators, using qualitative content analysis (Schreier 2012) to summarize findings for this round and identify statements for the rating task in subsequent rounds. For each of the questions, each investigator read over the text responses of each participant several times to understand the content and range of ideas expressed. By looking for similarities among these ideas, each investigator first grouped participants' responses into a preliminary set of broad thematic categories (e.g. "fire"), then further organized responses into more specific subthemes within those categories (e.g. "fire interval"). The investigators then shared their results with each other and worked toward consensus to define the set of themes and a manageable number of subthemes that maintained specificity and adequately captured respondents' ideas for each of the questions. The two investigators jointly prepared a draft set of statements to concisely describe subthemes for each of the questions, which were finalized by the full social science team. The themes and subtheme statements structured the presentation of round 1 findings and described the degree of consensus and variation in responses through summary text and key quotations (Schreier 2012).

The statements derived from round 1 were used for rating in rounds 2 and 3. These ratings were summarized (mean, standard deviation) and top ranks for round 2 were also tallied across respondents. In many cases the ratings were very close and with the small sample we focused on the general pattern of results rather than attempting to discern statistically significant differences. We present these results graphically in Figure 4 and Tables S1–S3 (Supporting Information) provide mean scores and standard deviations.

Results

Key Characteristics of Pine Barrens

Participants' open-ended responses for key characteristics in round 1 fell into five thematic categories: fire, landscape structure, plant and animal species, soil and surface characteristics, and recreation and aesthetics. In the sections below, we describe each category and highlight the verbatim wording of the statements developed for rounds 2 and 3 in ***bold italics***.

Fire. Fire was mentioned by 17 of the 18 first-round respondents as a key characteristic of pine barrens and was often the first thing listed in their open-ended responses. We developed three statements to capture these responses. Pine-barrens are ***fire-dependent systems*** characterized by fire-adapted trees such as jack pine that requires fire to reproduce, shrubs and woody plants that produce bountiful crops of nuts and fruit in the years after a fire, and deeply rooted grasses and forbs that develop a thick sod layer that protects insects and small animals below it as fire sweeps across the surface. They are ***maintained through periodic/recurring fire*** that promotes the openness of the community, particularly by killing off fast-growing trees such as aspen (*Populus tremuloides*), which can quickly encroach on barrens, especially those areas being restored after a long period of fire suppression. Respondents mentioned various intervals for conducting burns ranging from 2 to 15 years, though one person said that variations of up to 300 years have been documented and produce fires of different intensities with subsequent changes in species composition. These adaptations result in a ***fire-influenced architecture*** such as thermally pruned canopy trees (removal of lower branches by fire), dense clumps of small jack pine, and oak (*Quercus* spp.)"grubs" (shrubby post-fire regrowth from the underground root system).

Landscape Structure. The landscape-level structural characteristics of pine barrens were mentioned by 14 of the 18 first-round participants, with openness and size factoring into many of the statements we developed for subsequent rounds of rating and ranking. Pine barrens are characterized by a ***relatively open canopy***, overall, less than 25% of canopy cover and frequently less, including ***large open areas without any canopy trees***. In other areas, canopy is composed of ***scattered single trees*** and ***clumps of trees***, which together produce a ***patchy mosaic of trees, shrubs, and grasses***. Respondents varied widely in how they talked about the numbers and spatial arrangement of trees in the landscape, but generally agreed that pine barrens were structurally diverse. As summarized by one respondent, "Pine barrens are not a uniform looking landscape. Pockets of varying tree density and age are scattered unevenly on the landscape, because of the varying intensity of a major management tool, fire, on its effects."

For this mosaic to function as a community, ***large areas*** are needed for restoration, at least hundreds of hectares if not thousands. This allows for frequent low-intensity fires and occasional higher intensity fires to produce a ***dynamic, temporally changing horizontal structure*** along with a ***variable vertical structure*** that makes pine barrens visually and biologically diverse. As one respondent explained: "This habitat type needs to be managed on a landscape level. We should aim to have managed property at least 5,000 acres or more and corridor

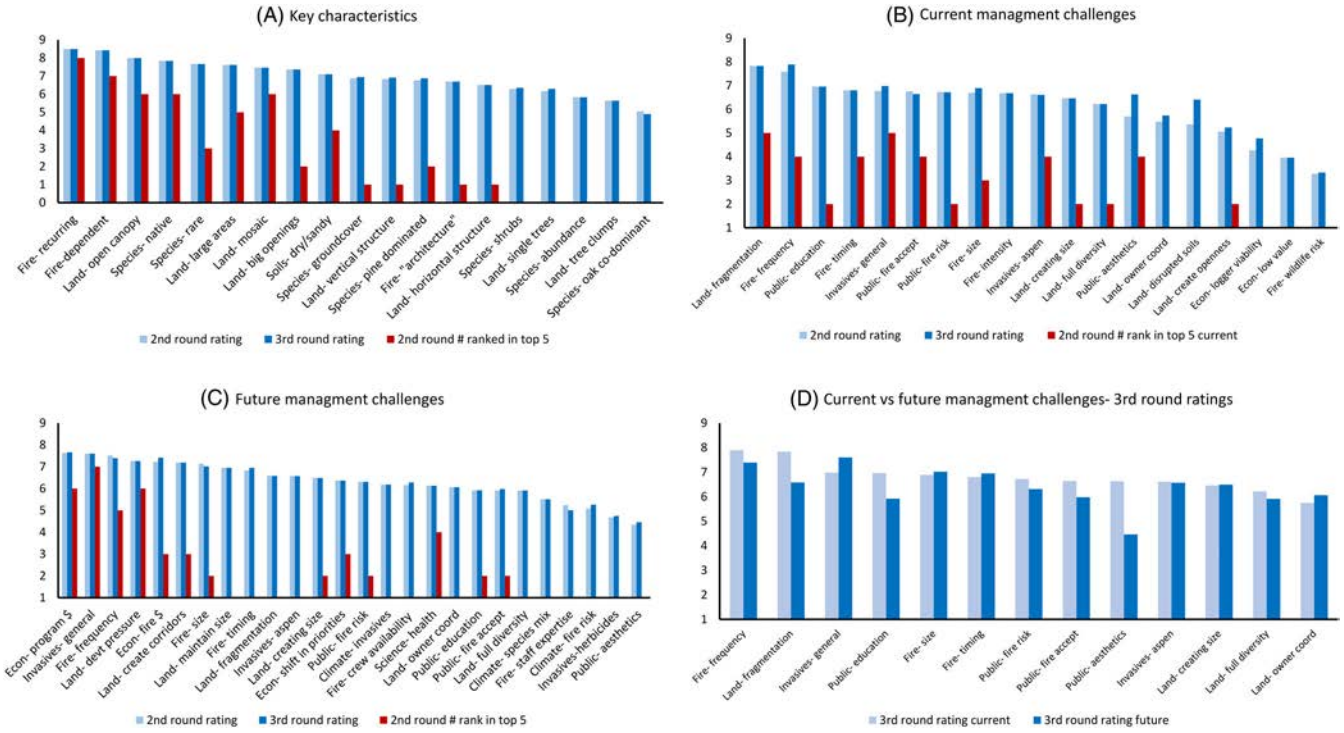

Figure 4. Ratings and rankings of statements by participants in Delphi rounds 2 and 3: (A) key characteristics; (B) current challenges; (C) future challenges; (D) current versus future challenges—third-round ratings of common statements. First term in the item label references the thematic category and subsequent wording paraphrases the specific statement rated or ranked. See text and Tables S1–S3 (Supporting Information) for complete wording used in the Delphi questionnaire.

properties managed with timed sales or other means in between so that wildlife species requiring this habitat type can move from one to another."

Species. All but one respondent mentioned species-level characteristics of pine barrens, though some focused more on the structure and fire processes that provide the landscape conditions for species while others wrote detailed lists of individual rare and threatened species for which pine barrens provided critical habitat. As it was difficult to develop statements to cover this latter set of respondents, we created more general descriptions of plants and animals. Pine barrens are ***pine-dominated systems***, which in the northern Great Lakes Region tend to be of jack pine and red pine, though on richer sites and toward the southern end of its range they can be ***oak co-dominant (bur)*** (i.e. bur oak, *Quercus macrocarpa)*. Below the canopy level, pine barrens have a ***prominent shrub cover of scrub oak and ericaceous*** (heath) ***species*** and a ***thick groundcover of grasses and forbs***. Shrub species mentioned include berry producers, especially blueberry and bearberry (*Arctostaphylos uva-ursi*), and understory species include sweet-fern (*Comptonia peregrina*) and bracken fern (*Pteridium aquilinum*), the latter of which can dominate in low-lying frost-pockets.

Along with these prominent species, pine barrens also support ***rare species of concern***. Respondents did not mention any plants by name but several people mentioned birds including the upland sandpiper (*Bartramia longicauda*), nighthawk (*Chordeiles minor*), and prairie warbler (*Setophaga discolor*); reptiles and amphibians including the Eastern hog-nosed snake (*Heterodon platirhinos*) and spadefoot toad (*Scaphiopus hammondi*), and insects including the Karner blue butterfly (*Lycaeides melissa samuelis*) and inland barrens buckmoth (*Hemileuca maia*). The prevalence of nut- and berry-producing plants also make pine barrens a place of ***abundant wildlife*** such as deer (*Odocoileus virginianus*), bear (*Ursus americanus*), and turkey (*Meleagris gallopavo silvestris*). They also provide critical habitat for sharp-tailed grouse and other grassland game birds. In summarizing the species character of high-quality pine barrens, respondents said they should aim toward ***predominantly native species*** and that aggressive management of invasive exotics such as spotted knapweed (*Centaurea biebersteinii*) is needed on some sites.

Soil and Surface Characteristics. About half of the 18 respondents mentioned soil and surface characteristics, foremost the ***dry, sandy soils*** that underlie the more visible structural and species characteristics of pine barrens. The excessively drained soils are low in fertility and limit water availability to plants, giving competitive advantages to fire- and drought-adapted species. Varied topography, however, provides for

some moisture differences and, combined with variation in soil depth, can result in unique features such as lakes, parabolic sand dunes, and rock outcrops.

Recreation and Aesthetics. Five of the 18 respondents mentioned social issues directly and, because most comments related to the biophysical conditions of pine barrens covered above, we did not develop any statements for rating and ranking in subsequent rounds. For example, respondents mentioned that prominent ericaceous species make pine barrens desirable locations for berry picking, the presence of rare animal species provides opportunities for birding and wildlife viewing, and abundant wildlife makes pine barrens good places for hunting. Two respondents mentioned the aesthetic challenges that pine barrens pose for a public that is accustomed to typical Northwoods scenery: one of them stated that this ecological community is "not well appreciated by mainstream American culture—it does not appear 'productive' or healthy (lush and green)." The other suggested that experiencing the barrens can lead to greater appreciation: "Pine barrens are perceived by the casual observer of being devoid of diversity and wildlife, but to those out experiencing pine barrens by walking through them or hunting, they are aware of the abundance of diversity and their ability to support a variety of wildlife."

Ratings and Ranking of Pine Barrens Key Characteristics

Statements for the key characteristics of pine barrens were rated and ranked for importance (Fig. 4A, Table S1, Supporting Information). In terms of importance, all but one of the 19 statements (oak co-dominant) were rated above the midpoint of the nine-point importance scale. Nine statements received ratings of seven or higher on the scale and these nine also garnered nearly all of the top-five rankings. Two of the three fire statements (recurring fire, fire-dependent system) were deemed most important in both rating and ranking. Structural characteristics and species characteristics alternated top rankings and ratings. The single soil statement was rated lower but ranked among the top five. There was little change in respondents' ratings between rounds 2 and 3 and no change at all among the top-nine-rated statements.

Current and Future Management Challenges

Open-ended responses for current management challenges in round 1 were grouped into five thematic categories: fire, landscape, invasive species, social, and economic. Future management challenges followed these same themes plus climate change and scientific. Because many of the same statements applied to both current and future management challenges, we present them jointly below and note differences where present.

Fire. Fire was mentioned as a current challenge by all 18 respondents and as a future challenge by 14 respondents. Three statements pertained to both current and future challenges—***fire frequency: constraints to use fire frequently enough***; ***fire size: constraints to burn large enough area***; and ***fire timing: constraints to use fire throughout the year (outside typical early spring burn season)***. Each of these issues is critical to pine barrens management to maintain open conditions that encourage development of a diverse ground layer and control the growth of undesired trees.

The fire timing issue also related to four other issues, with ***fire intensity: getting or permitting high-intensity fires*** and ***risk to wildlife from fire*** mentioned as current challenges and ***availability of fire crews/staffing outside typical early spring burn season*** and ***staff expertise to use fire as a management tool*** mentioned as future challenges. A few respondents mentioned that early spring burns tend to be the norm in the northern Great Lakes Region, but that during this time the soils are often cold and wet and fires do not get hot enough to "exhaust underground hardwood carbon reserves and burn through thick duff layers." Burning outside this time carries its own challenges: later in the spring can be controversial because of potential risk to newborn birds and other wildlife; fall burns often have a short window, and summer burns are hampered by fire crews that increasingly leave to fight western wildfires. These opportunities for more effective application of fire also face institutional constraints that include "safety concerns, cost, and the desire to keep trained staff and equipment available to respond to wildfires during weather conducive to burning."

Landscape. Landscape-related challenges were mentioned by 14 of the 18 respondents in terms of current challenges and by 9 in terms of future challenges. Four statements pertained to both current and future challenges—***land ownership fragmentation limits scale of restoration***; ***creating manageable barren size***; ***going beyond simple/macro structural changes to restoring full plant diversity***; and ***coordinating among multiple landowners***. Another two statements covered just current challenges—***disrupted soil conditions/furrowing from former pine plantations*** and ***conversion of closed canopy to open canopy***; while three additional statements pertained to only future issues—***development pressures at the wildland-urban interface***; ***creating corridors to connect isolated barrens habitat***; and ***maintaining manageable barren size***.

A number of these landscape-related statements conveyed nuanced distinctions of the need to aggregate and coordinate management over large areas of land. As one respondent put it: "A small barrens property is not very worthwhile surrounded by heavily wooded landscape." In this respect, effective pine barrens management is increasingly challenged by private land parcelization and development, which result in unmanaged patches with mature trees ("maple-ization") and seasonal homes that make large burns more difficult. Other statements described the technical challenges of restoration, particularly on lands under restoration after a long period of fire suppression and

forest cover of hardwoods or pine plantations. One respondent itemized the challenges from both types of conditions: for hardwoods, "underground vegetative reproduction via stump and root sprouting takes decades of repeated burning to exhaust belowground carbon reserves," and for plantations, "conversion to grassland is comparatively rapid when compared to hardwood forests, but vegetation can be depauperate and may require active seeding."

Social. Eleven respondents mentioned social issues as current challenges and eight as future challenges, and the four statements we developed pertained to both periods. Many of these individuals mentioned the challenge of ***public acceptance of fire as a management tool***, along with the related ***public concern about fire risk***. Here, respondents talked about the negative social perceptions that all fire is bad (the "Smokey Bear syndrome") and fear that prescribed fire will escape and damage residential property. Several respondents also mentioned ***public concern about barrens aesthetics***, and that its open qualities are unfamiliar to those who are "simply more interested in a forested landscape" and "does not look 'productive'—like a desert." The removal of trees to restore barrens was also reported to carry negative association among the public and even some forest managers, the latter of whom tends to believe that "smaller is better and leaving trees after harvest is better." Finally, most who mentioned social issues talked about the need for ***public education about the value of pine barrens and their restoration***. Here participants mentioned communicating the importance of fire as the "life-blood" of these ecosystems and promoting the values of barrens to "gain buy-in." These values included recreational opportunities such as hunting, watching wildlife, and berry-picking; their historic importance; and the ecosystem services they provide.

Invasives. Three issues related to exotic or native invasives were mentioned by three respondents as current challenges and by six as future challenges: ***invasive species management*** in general, ***killing aspen and preventing continued resprouting***, and ***agency/organization willingness to use herbicides*** to control both invasive exotics and resprouting aspen. Invasive exotics mentioned included plants like garlic mustard (*Alliaria petiolata*) and spotted knapweed, and in addition to native aspen, which is a major problem on forested lands that are being restored to pine barrens, respondents also mentioned native white pine (*Pinus strobus*) and maple (*Acer rubrum)*, the latter of which has led to mesophication, "where dry grasslands succeed to increasingly wetter forest cover that becomes self-reinforcing, for example with the development of thick forest floor (duff) layer."

Economic. Six respondents mentioned economic issues under both current and future challenges. For current challenges, these included the ***low timber value of pine barrens*** and related issue of ***economic viability for loggers***. Some land managers, because their budgets for pine barrens restoration are partly tied to timber sales, must creatively finance restoration work such as bundling sales for timber removals on restoration parcels with sales on more productive stands. Future economic challenges included the ***availability of fiscal resources to apply fire as a management tool***; ***maintaining a viable restoration program in the face of decreasing budgets***; and ***maintaining a viable restoration program in the face of shifting priorities***. These latter two concerns applied not only to existing properties but also for land acquisition of remaining unprotected pine barrens. Of this need, one respondent remarked: "It is impossible to buy and conserve this much land and private landowners are unable or unwilling to manage land in an open state."

Climate Change. Climate change was mentioned as a future management challenge by six respondents, and while it was often written about relative to other themes such as fire and invasive species, the centrality in which respondents included it warranted separate statements: ***climate change-increasing risk related to invasive species*** such as movement of insect pests like the southern pine beetle (*Dendroctonus frontalis*); ***climate change-increasing fire risk*** with the potential for periods of hotter and drier weather as well as stress to existing communities making severe fires more probable; and ***climate change-altering species composition*** as climate change drives phenological shifts of pine barrens vegetation like jack pine, which is already at the southern edge of its range on some barrens sites. One respondent wrote about balancing climate change-related concerns with pine barrens restoration: "Predicted climate change (increasing temperatures) should bode well for these ecosystems, but will cause people to have concerns with carbon emissions affiliated with burning. Burning to maintain pine barrens vastly outweighs climate change concerns in this context."

Science. One person explicitly mentioned the need for better science as a future management challenge: ***We need a better scientific understanding of what constitutes a healthy barrens ecosystem and how to achieve it*** through available restoration techniques. Related to this, another respondent mentioned that "many managers… don't really know what a historic pine barrens looked like, and thus tend to aim for a vegetation structure that is overly simplistic (the extremes being lacking trees entirely, or conversely having appropriate woody structure but a ground layer dominated by just a handful of species, such as Pennsylvania sedge [*Carex pensylvanica*] or bracken fern [*Pteridium aquilinum*])."

Ratings and Rankings of Current and Future Management Challenges

Like the key characteristics statements, pine barrens management challenges were both rated and ranked for importance. Seventeen of the 20 current challenge statements were rated above the midpoint of the nine-point importance scale, though only two received ratings of seven or higher ("ownership

fragmentation" and "fire frequency") (Fig. 4B, Table S2, Supporting Information). As with the findings for key characteristics, there was little movement of participants' ratings of current challenges between rounds 2 and 3, though "public concern for aesthetics" and "disrupted soil conditions" did show noticeable rises in round 3. In round 3, all four social issues placed within the top half of statements in their importance ratings.

All but one of the 26 future challenge statements were rated above the midpoint of the importance scale and seven received ratings of seven or higher: two economic issues (program budget, fire budget), one invasive plant issue (exotic invasives), two fire issues (frequency and size of burns), and two landscape issues (development pressures and creating corridor connections) (Fig. 4C, Table S3, Supporting Information). The four highest-rated issues were also ranked among the top five by at least a third of participants (program budget, exotic invasives, fire frequency, and development pressures) along with the one science-related issue of understanding ecosystem health. Again, participants' ratings showed little movement between rounds 2 and 3.

A subset of statements mentioned by participants as both current and future challenges allowed for a comparison of round 3 ratings (Fig. 4D). Given the small participant pool size, we did not test for the significance of changes in ratings, but the largest rating increase was for exotic invasives and the largest drops were for public education and public concern for aesthetics. Indeed, all four social issues showed a downturn in ratings as future challenges.

Discussion

Pine barrens of the northern Great Lakes Region of the United States and Canada have a rich social-ecological history that shapes current restoration efforts. While our panel of experts detailed the key characteristics important in the restoration process, they also identified a range of potential barriers with how pine barrens are perceived by the public and even foresters that could limit broader acceptance of their restoration. Understanding these barriers precipitated our research and involvement in the Lakewood Southeast Project, and the information gleaned from the Delphi survey formed the important first phase of our broader investigation to understand how the key characteristics of pine barrens relate to public preferences.

According to the Delphi panel, the key characteristics of landscape structure that help define pine barrens include large open areas without any trees, as well as considerable horizontal variation that includes a patchy mosaic of open areas mixed with clumps of trees and single trees. Along with a varied vertical structure of trees, shrubs, and groundcover, these structural landscape characteristics can produce considerable visual diversity when pine barrens are managed over extensive land area. While very little visual preference research has been done on pine barrens, work on forest environments with varying degrees of openness provides additional clues on how vegetation can be manipulated to create aesthetically pleasing effects and minimize visual impacts (e.g. Ribe 1989).

The key characteristics of fire are also fundamental to pine barrens as described by our panel. Fire not only shapes the visual landscape by keeping it open and varied but also makes barrens productive for a diverse and abundant assemblage of species. The legacy of negative perceptions of fire is longstanding, and while wildfire risk continues to be a valid and important challenge (McCaffrey & Olsen 2012), public acceptance of fire as a management tool in reducing wildfires and restoring the health of fire-dependent landscapes may be increasing more than our panel was aware of. Studies, including previous work of our own within the Lakewood Southeast Project area (Floress et al. 2018), show considerable support for its use as a management tool, with support increasing over time as a result of increased public familiarity and agency trust (McCaffrey & Olsen 2012). Finally, while fire can have significant negative effects on visual preferences (e.g. Taylor & Daniel 1984), in places like Wisconsin that receive considerable precipitation in the spring and early summer, the visual effects are usually short-lived.

The species characteristics of pine barrens mentioned by the panel provide opportunities to better connect people with the landscape and to build awareness through experiences that can lead to its appreciation and acceptance (Gobster 1999). The bumper crop of berries resulting from burns provides family-oriented recreation that land management agencies can promote to local residents and visitors, while rare and abundant wildlife can attract birders and hunters. The challenge of public education cited by the panel is often better addressed by self-guided or guided experiential opportunities than by structured informational materials and presentations, though the former can often lead to interest in the latter (Gobster 1999).

As we noted in the findings, the importance ratings of key characteristics and current and future management challenges showed little movement between rounds 2 and 3. This would seem to indicate that the experts felt relatively confident in their initial ratings and the ratings of the other participants did little to sway their feelings. While our final sample sizes for these rounds were quite small and not generalizable to other places or ecosystems, we nonetheless feel fairly confident that the ratings generally reflect the consensus of the panel and that further rounds of the Delphi were not necessary (Delbecq et al. 1975).

In our using the Delphi as a precursor to a public preference survey, perhaps more interesting was the finding that the four social statements rated as important current challenges dropped in importance in consideration of future challenges. Because our survey did not provide for an opportunity to follow up with respondents, we can only surmise why this was the case. One potential explanation is that respondents felt that, in time, public acceptance would increase as people become more familiar with pine barrens and their management. To some extent, this is consistent with previous research on fire acceptance (Gobster et al. 2016) and is the goal of most conservation education programs (Derek Scasta et al. 2015). A more likely explanation, however, is that the specter of other challenges such as invasive species and maintaining adequate budgets to finance restoration programs simply outweighed concerns for social issues.

Further research is needed to understand how restoration programs can best meet the expectations of public stakeholders and gain their increased support, and the next phase of our work will use a discrete choice experiment or DCE (Louviere et al. 2000) to examine how varying the key characteristics of pine barrens identified in this Delphi process might affect public stakeholder preferences. In the DCE, different levels of treatment attributes such as tree density (5–35%) and fire interval (3–30 years) are systematically paired with each other in digitally constructed visual choice scenarios, and by having participants select their preferred scenes across a series of scenarios, the relative preference weights of the attributes and attribute levels can be derived. With this combined Delphi-DCE approach, stakeholder preferences can be directly translated into management-relevant alternatives to help public land managers make informed decisions in balancing social and ecological goals.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Key characteristics ratings (standard deviations in parentheses) and rankings.

Table S2. Current management challenges ratings (standard deviations in parentheses) and rankings.

Table S3. Future management challenges ratings (standard deviations in parentheses) and rankings.

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