The state, resilience, and potential future of oak-dominated forests in the Driftless Area of the midwestern U.S.

by

Tricia Gorby Knoot

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Forestry

Program of Study Committee:
Lisa A. Schulte, Major Professor
Nancy Grudens-Schuck
James R. Miller
Brian Palik
Mark Rickenbach

Iowa State University

Ames, Iowa

2008

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Forest surveys over the last several decades indicate a decline in oak regeneration in the midwestern United States with a high potential for future replacement by later successional forest types. The current state of oak systems may be nearing critical thresholds, which, if reached, their restoration could become markedly more challenging, if not impossible. Through a combination of qualitative and quantitative research methods, I evaluated the state, resilience, and potential future of oak forest ecosystems within the Driftless Area of the midwestern U.S., with the intention of providing information that can inform the design of timely and targeted oak-specific policy and management strategies. In-depth interviews with 32 regional natural resource professionals suggested a widespread decline in the extent of oak-hickory timberland and a shift towards more shade-tolerant forest types (i.e., maple-basswood forests). Analyses of forest surveys, collected through the U.S .Forest Service Forest Inventory and Analysis (FIA) national program, supported interviewees' perceptions of the trajectory of forest change and revealed that the composition and age structure of timberland across ecoregion subsections is becoming less variable. I also found a general shift towards the elm-ash-cottonwood forest type group; system state deemed undesirable by the professionals. The interviewees identified private landowner decision making as central to oak regeneration success. Ecological, economic, and social factors—including but not limited to deer herbivory, understory competition, forest parcelization, exurban housing development and short land tenure—were thought to constrain landowner decision making regarding oak at multiple spatial scales, and to decrease system resilience. Conversely, interpersonal relationships between natural resource professionals and landowners, in addition to economic incentives, were identified as promoting landowner adoption of oak management practices. A holistic and in-depth understanding of the complex system relationships, feedbacks, thresholds, and uncertainties offered potential leverage points from which to enhance oak system resilience. Experimental knowledge (e.g., quantitative evaluation of thresholds related to understory competition and the economic expense of oak regeneration) is now needed to isolate cause and effect and provide access to those seeking action.

CHAPTER 1.
GENERAL INTRODUCTION

Ecosystems throughout the world have been profoundly affected by anthropogenic factors resulting in vast changes to land use, biotic communities, and ecosystem function; evidence that human systems are now tightly coupled with most, if not all, ecological systems (Vitousek et al. 1997). This coupling has often left ecosystems less able to adapt to natural and anthropogenic disturbances, resulting in undesirable and sometimes sudden regime shifts (Scheffer et al. 2001). To avoid such shifts, ecologists have more recently stressed the need for developing mechanisms that enhance the adaptive capacity, or resilience, of systems (Scheffer et al. 2001, Gunderson and Holling 2002, Walker et al. 2002). Building resilience in coupled human and natural systems (i.e., social-ecological systems) requires an integrated understanding of ecological and social system components and processes, with attention towards identifying key feedbacks, thresholds, and uncertainties (Walker et al. 2002, Carpenter et al. 2006, Liu et al. 2007).

The oak-dominated forests of the midwestern United States provide a valuable opportunity to assess the resilience of social-ecological systems in the context of a disturbance-dependent forest type that is embedded in a landscape composed of diverse ownerships. Oak (*Quercus* spp.) forests in North America are considered critical habitat for conserving regional biodiversity (McShea and Healy 2002, Rizzo and Garbelotto 2003, Fralish 2004). In the eastern and midwestern U.S., oaks have been an important forest component for at least the last 10,000 years (Abrams 1992). Consequently, oak forests currently provide vital habitat for numerous wildlife and plant species that have adapted to the ecological conditions they afford (Fralish et al. 1991, McShea and Healy 2002, Rodewald and Abrams 2002).

However, the current state of oak systems may be nearing critical thresholds; if reached, restoration may become markedly more challenging, if not impossible (Nowacki and Abrams 2008). The historical prevalence of oak in the eastern and midwestern U.S. is attributed partly to centuries of burning by American Indians, and current oak dominance has been linked to the intensive logging, fire, and grazing activities of Euro-American settlers (Abrams 1992, Johnson et al. 2002). In both cases, anthropogenic disturbance has promoted the regional dominance of oak; oaks typically are more fire adapted than later-successional tree species and readily stump sprout under the appropriate conditions (Burns and Honkala 1990). Other ecological and social factors—increased herbivory by white-tailed deer (*Odocoileus virginianus*) (Rooney and Waller 2003), pests and disease issues (Baughman and Jacobs 1992), and less-intense or ill-planned timber harvesting (Abrams and Nowacki 1992)—have further reduced the competitiveness of oak and led to the "mesophication" of forests (i.e., shift in forest conditions that favor shade-tolerant, broad-leaved, forest types; Nowacki and Abrams 2008). Taken together these factors suggest that, without direct human intervention, the future of regional oak dominance and the retention of associated biodiversity are uncertain, if not imperiled (Nowacki and Abrams 2008).

The overall goal of my dissertation research was to identify strategies for building resilience in midwestern oak forest ecosystems that are both ecologically- and socially-relevant. In the midwestern U.S., the majority of oak forestland is privately owned (US Forest Service 2006); thus, oak system resilience is tied to the collective decisions made by numerous and diverse landowners (Butler and Leatherberry 2004). Quantitative methods are useful for answering many critical ecological and social questions. However, qualitative social science research methods offer further insight into complex issues for which little knowledge exists and innovative flexible strategies are needed (Strauss and Corbin 1990). Through a combination of quantitative and qualitative research methods, I evaluated the state, resilience, and potential future of oak forest ecosystems within the Driftless Area of the midwestern U.S., with the intention of providing information that can inform the design of timely and targeted policy and management strategies that can ensure the future provisioning of ecosystem goods and services associated with oak ecosystems.

THESIS ORGANIZATION

This dissertation is composed of four papers that were written for publication in scientific journals and one paper that was written as an extension and outreach publication for private landowners. Chapter 1 contains a general introduction of my dissertation research. Chapter 2 evaluates the key ecological and social features that influence oak conservation and restoration on private forestlands in the Driftless Area of the Midwest. Chapter 3 focuses on the temporal dynamics of forest ownership and how the changing social landscape influences forest management, and specifically oak restoration on private forestlands. Chapter 4 provides a holistic systems analysis of the oak social-ecological system, identifying feedbacks, thresholds, system uncertainties, and the preferred attributes of future forest resources as identified by key changes agents in the region. Chapter 5 follows with a spatially explicit quantitative assessment of forest change in the study region. Chapter 6 is written as an extension and outreach publication for private landowners and highlights the ecology and management requirements of oak. Chapter 7 concludes with general insights gained from this project.

Data acquisition, statistical analysis, and the preparation of the text were the responsibility of the candidate; Dr. Lisa A. Schulte gave guidance and editorial advice on all chapters. In addition, several of my dissertation committee members (Dr. Nancy Grudens-Schuck, Dr. Brian Palik, and Dr. Mark Rickenbach), a faculty member at Iowa State University (Dr. John Tyndall), and an employee of the US Forest Service (Mark Hatfield), provided a combination of project guidance, advice on data acquisition, and editorial advice, and appear as co-authors on various chapters that will be submitted to scientific journals.

LITERATURE CITED

Abrams, M.D. 1992. Fire and the development of oak forests. *Bioscience* 42(5):346-353.

Abrams, M.D., and G.J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. *Bulletin of the Torrey Botanical Club* 119:19-28.

Baughman, M. J., and R. D. Jacobs. 1992. *Woodland owners' guide to oak management.* Pub-FO-05938. Minnesota Extension Service, University of Minnesota, St. Paul, MN, USA.

Burns, R.M., and B.H. Honkala, technical coordinators. 1990. *Silvics of North America: hardwoods.* Agriculture Handbook 654, vol.2. U.S. Department of Agriculture, Forest Service, Washington, DC., USA.

Butler, B.J., and E.C. Leatherberry. 2004. America's family forest owners. *Journal of Forestry* 102(7):4-9.

Carpenter, S.R., R. DeFries, T. Dietz, H.A. Mooney, S. Polasky, W.V. Reid, and R.J. Scholes. 2006. Millennium Ecosystem Assessment: Research needs. *Science* 314(5797):257-258.

Carpenter, S.R., and L.H. Gunderson. 2001. Coping with collapse: ecological and social dynamics in ecosystem management. *Bioscience* 51(6):451-457.

Fralish, J. S. 2004. The keystone role of oak and hickory in the central hardwood forest. Pages 78-87 in M.A. Spetich, editor. *Upland oak ecology symposium: history, current conditions, and sustainability.* Gen. Tech. Rep. SRS-73. USDA Forest Service, Asheville, NC, USA.

Fralish, J. S., F. B. Crooks, J. L. Chambers, and F. M. Harty. 1991. Comparison of presettlement, second-growth and old-growth forest on six site types in the Illinois Shawnee Hills. *American Midland Naturalist* 125:294-309.

Gunderson, L.H., and C.S. Holling, editors. 2002. *Panarchy: understanding transformations in human and natural systems.* Island Press, Washington, D.C., USA.

Hessburg, P.F., J.K. Agee, and J.F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras. *Forest Ecology and Management* 211:117-139.

Jacobs, R.D., and R.D. Wray. 1992. *Managing oak in the Driftless Area*. Publication number BU-05900. Minnesota Extension Service, University of Minnesota, St. Paul, MN, USA.

Johnson, P.S., S.R. Shifley, and R. Rogers. 2002. *The Ecology and Silviculture of Oaks.* CABI Publishing, New York, NY, USA.

Liu, J., T. Dietz, S.R. Carpenter, M. Alberti, C. Folke, E. Moran, A.N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C.L. Redman, S.H. Schneider, and W.W. Taylor. 2007. Complexity of coupled human and natural systems. *Science* 317(5844):1513-1516.

McShea, W. J., and W. M. Healy. 2002. Oaks and acorns as a foundation for ecosystem management. Pages 1-9 in W. J. McShea and W. M. Healy, editors. *Oak forest ecosystems: Ecology and management for wildlife.* The Johns Hopkins University Press, Baltimore, Maryland.

Nowacki, G. J., and M. D. Abrams. 2008. The demise of fire and “mesophication” of forests in the eastern United States. *Bioscience* 58:123-138.

Rizzo, D. M., and M. Garbelotto. 2003. Sudden oak death: endangering California and Oregon forest ecosystems. *Frontiers in Ecology and the Environment* 1:197-204.

Rodewald A. D., and M. D. Abrams. 2002. Floristics and Avian Community Structure: Implications for Regional Changes in Eastern Forest Composition. *Forest Science* 48:267-272.

Rooney, T. P., and D. M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management* 181:165-176.

Scheffer, M., S.R. Carpenter, J. Foley, C. Folke, and B. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* 413:591–596.

Strauss, A., and J. Corbin. 1990. *Basics of qualitative research: grounded theory procedures and techniques.* Sage Publications, Newbury Park, CA, USA.

US Forest Service. 2006. *Forest inventory and analysis DataMart*, version 3.0. Available online at http://fiatools.fs.fed.us/fiadb-downloads/fiadb3.html; last accessed August 2, 2008.

Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo. 1997. Human domination of Earth's ecosystems. *Science* 277(5325):494-499.

Walker, B., S.R. Carpenter, J. Anderies, N. Abel, G.S. Cumming, M. Janssen, L. Lebel, J. Norberg, G.D. Peterson, and R. Pritchard. 2002. Resilience management in social–ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology* 6(1):14 [online] URL: http://www.consecol.org/vol6/iss1/art14.

CHAPTER 2.
OAK CONSERVATION AND RESTORATION ON PRIVATE FORESTLANDS: NEGOTIATING A SOCIAL-ECOLOGICAL LANDSCAPE

A paper submitted to *Restoration Ecology*

Tricia G. Knoot, Lisa A. Schulte, and Mark Rickenbach

ABSTRACT

In the midwestern United States, oak (*Quercus* spp.) forests are considered critical habitat for conserving biodiversity and are a declining resource. Ecological conditions such as deer herbivory and competition from more mesic broad-leaved deciduous species have been linked to poor oak regeneration. In the Midwest, where up to 90% of forestland is privately owned, decisions by individual landowners define success of regional restoration efforts. We sought to determine factors that serve as direct and indirect constraints to oak restoration and identify opportunities for improving restoration success. We conducted in-depth qualitative interviews with 32 natural resource and forestry professionals working in the Midwest Driftless Area, an area of high biodiversity and conservation value. We found that most professionals anticipate that oak will remain only a component of the future forest. Furthermore, they identified the pervasive unwillingness of landowners to accept oak restoration practices as a primary driving force of regional forest change. The professionals perceived that the attributes of oak restoration practices, in conjunction with landowner objectives, limited the successful adoption of oak restoration practices, and offered examples of how ecological and social context further constrained successful landowner decisions regarding oak. Professionals emphasized the importance of government cost-share programs and long-term personal relationships to securing landowner acceptance of oak restoration practices. However, given finite societal resources, ecologically- and socially-targeted approaches were viewed as potential ways to optimize regional success.

INTRODUCTION

Oak (*Quercus* spp.) forests in North America are considered critical habitat for conserving regional biodiversity (McShea & Healy 2002; Rizzo & Garbelotto 2003; Fralish 2004). In the midwestern and eastern United States, oaks have been an important forest component for at least the last 10,000 years (Fralish et al. 1991; Abrams 1992), and their long-term prevalence is, in part, attributed to millennia of human land management (Abrams 1992). Consequently, oak forests currently provide vital habitat for numerous wildlife and plant species that have adapted to the ecological conditions they afford (Fralish et al. 1991; McShea & Healy 2002; Rodewald & Abrams 2002). Forest surveys in the midwestern and eastern U.S., however, indicate an overall lack of oak regeneration along with a high potential for future replacement by later successional forest types (e.g., Nowacki et al. 1990; Taylor & Lorimer 2003). Fire suppression over the last century has accelerated the process of succession from oak-dominated forests (Nowacki & Abrams 2008). Moreover, other ecological and social factors—increased herbivory by white-tailed deer (*Odocoileus virginianus*) (Rooney & Waller 2003), pests and disease issues (Baughman & Jacobs 1992), and less-intense or ill-planned timber harvesting (Abrams & Nowacki 1992)—have further led to degraded forest conditions and have reduced the competitiveness of oak. Taken together these factors suggest that, without direct human intervention, the future of regional oak dominance and the retention of associated biodiversity are uncertain, if not imperiled (Fralish 2004; Nowacki & Abrams 2008).

To address this issue, natural resource agencies in the midwestern U.S. have identified oak restoration and management as a top priority (Iowa Department of Natural Resources 2005; Wisconsin Department of Natural Resources 2005); however, a comprehensive approach to successful regional oak regeneration has yet to be formulated. The majority of oak-dominated forests in the region are privately held (USDA Forest Service 2005), land uses are mixed, landowners are diverse, and ownerships are small (i.e., parcel size < 20 ha; Butler & Leatherberry 2004). Thus, to be effective, oak conservation and restoration strategies require a nuanced understanding of human-dominated landscapes, including a greater depth of understanding of social and economic constraints and opportunities that help determine realistic and socially acceptable restoration expectations (Miller & Hobbs 2007). Yet, the influence of social context on ecosystem change, biodiversity loss, and restoration potential, particularly in human-dominated landscapes, requires greater attention (e.g., Carpenter et al. 2006; Robinson 2006; Hobbs 2007). With regard to oak regeneration, forest ecologists have provided a more thorough understanding of oak ecology and management (Johnson et al. 2002) as compared to the paucity of knowledge on social factors that limit or promote oak regeneration. Moreover, the national trend of land parcelization and the concomitant increase in the number of landowners (Butler & Leatherberry 2004) signify that socially-informed solutions are becoming even more critical to the success of ecosystem conservation and restoration efforts in many regions (e.g., Rickenbach & Reed 2002).

In this study, we investigate the direct and indirect factors influencing oak forest conservation and restoration decisions on private forestlands in the biodiversity-rich Driftless Area of the midwestern U.S., and identify opportunities for influencing the future extent of these ecologically- and socially-valuable ecosystems. We interviewed regional natural resource and forestry professionals in pursuing three research questions:

1) What are the salient ecological and social factors that influence the adoption of oak forest conservation and restoration practices on privately-owned forestland?
2) How are these factors related?
3) What opportunities exist for optimizing oak forest conservation and restoration success?

In making forest management decisions, private landowners often rely on information gained through advice and guidance by natural resource and forestry professionals, such as public or private professional foresters, as well as from private loggers and those employed by sawmills (West et al. 1988). In such exchanges, professionals often can exert significant influence on landowner decision making and, ultimately, land management (Gass et al. 2006). As a result, natural resource and forestry professionals can be essential in the communication, dissemination, and eventual adoption of regional forest conservation goals; therefore, these professionals were central to our study.

METHODS

Study Region

The Midwest Driftless Area of the U.S., also known as the Paleozoic Plateau or Blufflands, is roughly 50,000 km^2 in size and covers portions of southeastern Minnesota, southwestern Wisconsin, northeastern Iowa, and a small area in northwestern Illinois. This region escaped the most recent glacial event, resulting in a rugged landscape composed of steep forested bluffs and rare geologic features. This landscape historically contained a patchwork of tallgrass prairie, bur oak (*Quercus macrocarpa* Michx.) savanna, oak-hickory (*Quercus spp.-Carya spp.*) forests, and sugar maple-American basswood (*Acer saccharum* Marsh.–*Tilia americana* L.) forests (Albert 1995). Given land use changes associated with Euro-American settlement, land cover now consists largely of agricultural lands positioned on the floodplains and level uplands, with oak-hickory and maple-basswood forests remaining on the steeper slopes (Prior 1991; Albert 1995). Currently, forests make up nearly one-third of landcover, 90% of which is privately owned (USDA Forest Service 2005).

In-depth Interviews

We adopted a qualitative research framework in this study because of the relatively unexplored nature of our topic and the presumed complexity of human decision making regarding oak restoration. The lead author conducted in-depth, semi-structured, qualitative interviews (Neuman 2003) with 32 natural resource and forestry professionals from October 2005 to May 2006. Interviewees were from the states that encompass the majority of the Driftless Area: Iowa, Minnesota, and Wisconsin. To identify and select potential participants, we used a purposive sampling approach, termed snowball sampling (Esterberg 2002). This non-random selection process allowed us to identify professionals with substantial experience and potentially diverse perspectives and was consistent with our goal of obtaining in-depth insight into the broad range of interviewee perspectives as opposed to calculating generalizations to a wider population. We targeted individuals who had regular contact with private landowners and direct experience with ecological, economic, and/or social facets of oak forest conservation and restoration. The interviewees possessed various natural resource backgrounds and consisted of publicly-employed foresters (n=13), other publicly-employed natural resource specialists (e.g., forestry extension specialists; n=5), privately-employed forestry professionals (e.g., consulting foresters; n=8), and those employed by the timber industry (e.g., sawmill owners and loggers; n=6). Twenty-seven of the 32 interviewees had worked as a natural resource professional for at least 10 years and 54% had at least 20 years of experience. Each interview followed a similar, open-ended question format, but the successive questions were guided by the participant's responses (Esterberg 2002). Over half of the interviews (n=17) were conducted in person; the remaining interviews were by telephone. Interviews averaged 49 minutes, but ranged between 23 to 107 minutes in length. All of the interviews were recorded and transcribed.

To analyze the interviews, we employed an iterative coding and theme development approach that began with open coding. In open coding, transcripts are coded based on the content of the interviews, not predefined concepts of what to look for. Initial codes were combined, recombined, and refined to develop themes and categories of themes, which reflected recurring sentiments expressed by natural resource and forestry professionals (Esterberg 2002). The data analysis was iterative; codes and themes were revisited and refined as each interview was coded. To aid with data management and coding, we used NVivo 7 (QSR International 2006), a qualitative data analysis software package. The initial coding process was conducted by the lead author; codes and themes were then confirmed as being consistent and reliable by the other two researchers. Here, we use direct quotations to present our findings, as they help accurately and succinctly exemplify themes. Interviewees were assigned pseudonyms to provide anonymity.

RESULTS

The majority of the interviewees predicted that oak forests will decline regionally, with widespread replacement by maple-basswood forests. In response to our inquiries into the causes underlying the potential loss of oak forests, most of the interviewees viewed private landowner management decisions as the driving factor in regional forest change. The salience of this factor reflected their sense that most landowners consistently make decisions that do not favor oak. For example, William, a consulting forester for nearly 20 years, shared his perception of the future of oak, remarking,

> I'd like to think we could keep an oak component, but I guess I've been in it long enough to know that . . . nature is going to take its course. Unless a lot more landowners step up to start doing something management-wise, the oak resource is going to continue to disappear.

To explain the general unwillingness of private landowners to manage their forestland in ways that encourage oak establishment, interviewees cited a variety of factors that they have found to affect landowner decision making. Our analysis revealed three overriding categories of themes. The first two define the challenges inherent in restoring oak: 1) the personal trade-offs of oak management and 2) the inhibitory effects of ecological and social context. Interviewees also suggested several opportunities for increasing the likelihood for oak restoration success, which represents our third category: multi-scale solutions toward oak forest restoration.

Category 1: Personal Trade-offs of Oak Management

In considering the potential for oak forest restoration, interviewees described their efforts to promote oak restoration in relative terms, comparing the attributes (ecological, economic, and social) of oak restoration with those of managing for later-successional forest types (i.e., maple-basswood). Their comparative framing of oak restoration appeared to reflect their role in the landowner decision-making process, which, they noted, typically consisted of advising landowners as to their forest management alternatives. Hence, our analysis of the interviews yielded insights into the landowners' personal trade-offs and risks associated with oak forest restoration and the cost-benefit analysis in which natural resource and forestry professionals often played a vital role.

Most interviewees found that the trade-offs involved with oak restoration—including the personal investment of resources, aesthetic preferences, and conflicting land management objectives—often exceeded landowners' perceived benefits, especially given a simpler and economically profitable alternative: managing for sugar maple. Many of the interviewees commented that high-grading, a practice in which the most profitable trees are removed from a forest stand, has regularly occurred on private lands throughout the region. The interviewees noted that high-graded stands are often ecologically inferior compared to previous conditions and have reduced long-term economic sustainability. However, the interviewees also noted that high-grading can provide the highest short-term economic gain for a private landowner and, with adequate sugar maple regeneration present, can result in promoting maple establishment. Along with high-grading, several professionals also commented that "hands-off" and selective harvesting approaches can promote maple establishment and require limited landowner personal investment of resources. Interviewees contrasted the use of these practices with a suite of oak restoration practices, which can provide for greater oak restoration success. For example, most interviewees recommended the repeated removal of understory plant competitors (e.g., manual removal, herbicide treatments, and/or prescribed fire), direct seeding of acorns, and/or planting of oak seedlings. At the same time, these recommended practices require a substantial long-term investment of landowner resources. As an example, the statement by Dan, a public forester for the last eight years, exemplified this perception:

> If I've got a sugar maple seed source and I can convert it to sugar maple. Bang! It's going to go; there's no expense on my part. If I want to go to oak, I may have to think about doing the shelterwood cut, doing the elimination of some of those understory species. . . . Going through the process is a long-term commitment versus just letting things happen.

In addition, many interviewees noted that most oak management practices—particularly harvesting the forest overstory—deterred landowner adoption for aesthetic reasons. The interviewees typically recommended several silvicultural prescriptions—differing in the timing and spatial extent of overstory removal—for restoring oak, such as clearcutting, shelterwood harvests (i.e., progressive removal of overstory trees over 10-15 years), and group selection, but most often cited clearcut harvesting as their preferred silvicultural tool. They commented that clearcutting is the most cost-effective approach to providing adequate light for oak establishment. Nevertheless, the professionals frequently noted landowner's unwillingness to accept the aesthetics of clearcutting and the other overstory removal techniques. For example, Walt, a public forester for over 20 years, remarked,

> Most landowners want the oak. Sometimes they don't like the idea that they have to open up the forest quite a bit to get sunlight to the ground and keep the oak coming back. [They] look at it as being too harsh, and wrecking their forest, and making it look bad for a number of years. . . . They aren't always willing to pay that price. . . . On one hand they want oak; on the other hand they don't want oak management.

Due to the various impacts of harvesting for oak regeneration purposes, interviewees noted that oak was often inconsistent with other objectives that landowners had for their land. For example, the professionals remarked that many landowners highly valued the recreation and privacy their forests afforded, and these values can conflict with impacts associated with oak regeneration methods. Leo, a consulting forester for over 20 years, shared his experience working with private landowners:

> It's rare to have clearcuts, for red oak anyway, because most private landowners . . . they don't want clearcuts. . . . Most private landowners don't want their woods flattened. That's why they've got woods, and that really is the only effective way of getting oak to regenerate. . . . With multiple use that most private landowners . . . use on their lands, I think it's unrealistic to expect a great deal of natural oak regeneration.

Through our analysis we found that the combined trade-offs, particularly given prevailing landowners' primary objectives, were considered to be beyond what most landowners were willing to accept. Tim, a public forester for over 10 years, offered an example of his experience with private landowners' decision making and their resolution to accept the alternative of managing for sugar maple forests:

> They're aware of the trade-offs. . . . I'll tell them if they want oak, and I'll tell them here's what you have to do to get oak. They'll say, "OK, I understand, I believe you. Now that I know, I guess I'm going to have to learn to love maple." . . . They still want the oak, but they don't want it that much.

Category 2: Inhibitory Effects of Ecological and Social Context

Interviewees offered examples of ways in which ecological and social context further constrained landowner decisions to manage for oak. Interviewees regularly cited four main factors related to ecological context that they have found to inhibit oak restoration: 1) deer herbivory, 2) competition by woody and herbaceous understory species, 3) diseases and pests of oak species, and 4) high site productivity potential. They spoke most often of deer herbivory and understory species competition and noted that these two factors increased the uncertainty of oak restoration success and the need for greater landowner investment. In particular, many professionals suggested that the full suite of oak regeneration methods can be required at a site—such as direct seeding or planting, removal of understory plant competitors, and protection of oak seedlings from deer herbivory—to achieve successful restoration.

In addition to ecological context, the professionals regularly described ways in which social context can reduce the likelihood that landowners adopt oak restoration practices. Specifically, interviewees shared with us how forest parcelization and associated residential development create operational constraints and influence individual perceptions of available oak restoration practices. For example, Grant, a public forester for nearly 30 years, commented on a recently developed forested area and the associated management challenges, remarking,

> It's 400 acres of really pretty timber . . . and it's almost all been developed in housing. Some of those lots are 10 acres. . . . Some of those folks are interested in doing some things in management, but now you have the problem with access; how to get equipment in and out of this place with high lines and septic systems, and everything else associated with housing. Also, that person probably is never going to do anything other than take out a few trees for firewood. It's their backyard.

Interviewees also noted that smaller parcels, with associated limited timber volumes, were unlikely to attract business from potential buyers due to reduced economies of scale. Therefore, several interviewees remarked that encouraging oak regeneration by harvesting even the maximum timber volume on a small forested parcel would not be economically feasible unless landowners coordinated harvests with their neighbors (i.e., cross-boundary cooperation; Kittredge 2005).

While our analysis revealed that social context could directly constrain oak forest restoration efforts, we also found an association between parcelization, residential development, and individual forest management preferences—namely aesthetics. Similar to the above sentiment by Grant that landowners living on small forest parcels viewed their acreages as "their backyard," several interviewees remarked that some small parcel owners were more attuned to the aesthetics of forest practices. Dan, a public forester for the last five years in the region, commented on the trend of parcelization and potential change in landowner perspectives on forest management:

> If [a private landowner] owned 160 acres and [their] house was in a 40 [acre parcel] and you say, . . . "Let's just manage everything except the area right around the house." Now we're asking people who own 40 acres to manage that 40 acres and

> they can't escape their management. . . . So they want to hold on to those big trees or what their aesthetic tells them that they want to hold on to.

Category 3: Multi-scale Solutions toward Oak Forest Restoration

We found that natural resource and forestry professionals encountered a variety of factors that have constrained oak restoration on private lands, but interviewees also shared success stories and offered potential changes to current programs and opportunities for additional mechanisms—cost-share programs, outreach efforts, and spatially targeted restoration—that could improve oak restoration regionally. They typically remarked on the importance of both federal and state cost-share assistance to encourage landowners to adopt oak restoration practices. The cost-share programs were viewed as reducing the economic burden of restoring oak, thereby partially removing a personal trade-off. Several interviewees also suggested changes to current programs, specifically the need for oak-specific incentives, which they posited could improve the likelihood of retaining oak at the regional scale. For example, these professionals noted that most cost-share programs did not support the multi-year management practices, such as repeated prescribed fire, needed for removing understory competitors that inhibit oak establishment over time. Several interviewees have also found that planting abandoned agricultural fields and pastures to oak, as financed through a federal cost-share program (i.e., the Conservation Reserve Program [CRP]), was highly successful due to limited competition from herbaceous and woody competitors. As restoration through planting oak in areas that are not currently forested does not entail the removal of mature trees, interviewees perceived these plantings as having greater acceptability among landowners. For example, Tim commented that "our best opportunities for growing oak are usually with new tree plantings like either on CRP [fields] or on abandoned pastures." Several interviewees therefore saw the continuation of governmental incentives designed to encourage landowners to plant oak in abandoned fields as having potential to contribute to regional oak forest conservation and restoration efforts.

In addition to cost-share assistance, many of the interviewees also spoke of the importance of one-on-one contact with landowners, thereby increasing a landowner's level of awareness regarding the lack of oak regeneration throughout the region and possibly on an individual's property. Rich, who has worked as a consulting forester and public forester for nearly 20 years combined, noted,

> You can do as many brochures and pamphlets; it doesn't quite have the same impact as walking through the woods. . . . They are in their woods, the forester is explaining what's going on, why there are no oak seedlings down here. . . . They may have never noticed it before.

However, several professionals suggested that one-time economic incentives and short-term personal contact have not necessarily resulted in the adoption of oak restoration practices. Instead, these professionals recommended a long-term process that, they have found, encouraged landowners to implement management practices that were conducive with oak establishment. For example, interviewees relayed stories of building relationships with landowners that often included introducing landowners to lower-impact management activities initially, with more intensive forest management approaches coming later. Todd, who has been employed as a public and consulting forester for 13 years combined, shared a story of the importance of repeat contact with a landowner:

> I have been working with [a landowner] for a few years and we have done two harvests. . . . So far [the harvests] have always been very selective harvest in the timber that is primarily maple, but there are a couple areas where there is oak in there. We're kind of sitting on those . . . I'm trying to wean her into this. . . . When I first met her, the idea of clearcut, absolutely not. . . . She is getting more and more okay with it. . . . Sometimes it takes a while.

While appropriate economic incentives and social connections were reported as valuable aids to encouraging landowners to adopt oak regeneration practices, many interviewees voiced concern over the shortage of natural resource and forestry professionals and spoke of the potential value of adopting a spatially targeted approach—identifying the most ecologically- and socially-suitable sites for oak restoration. Ecologically-suitable sites were often recognized as having fewer ecological constraints, such as sites that are less suitable for sugar maple recruitment, while social suitability for oak restoration was associated with compatible landowner goals and larger parcel sizes. For example, Grant noted, "Where clearcutting really works out is if a person has a big woodland and we take small chunks to work with. . . . Very few people are going to cut half their woods."

DISCUSSION

Despite the priority that natural resource agencies in the Midwest have placed on oak restoration, the results of our interviews suggest a questionable future for oak in a landscape composed primarily of small private landholdings. While oaks currently dominate the forested areas in our study region, we found that the land management decisions made by private landowners—as influenced by a combination of local ecological factors (e.g., understory plant competition) and endogenous (e.g., individual landowner aesthetic preferences) and exogenous (e.g., land parcelization) social factors—are shaping the composition of the region's forests and thus the future availability of habitat for oak-associated plant and animal species. Individual landowner decision making is a difficult process to untangle, especially given that landowners hold diverse values (Butler & Leatherberry 2004) and complex motivations for managing their forestlands (Bliss & Martin 1989). The heterogeneous landscape structure in which ownership patterns exist adds further complication (Crow et al. 1999). Our findings offer insights into the salient factors that constrain and promote landowner decision making regarding oak restoration. This information can be applied to designing appropriate mechanisms that improve the likelihood that oak-dominated forests and associated biodiversity persist within the midwestern landscape.

Conserving and restoring biodiversity on private lands, although vital (Bean & Wilcove 1997; Knight 2000), is a tricky process. It requires attention to private property rights while at the same time protecting the critical ecosystem goods and services valued by society (Knight 2000). We found that our interviewees have encountered widespread resistance by private landowners towards restoring oak, a tree species that holds tremendous societal value. Although the public benefit of oak was acknowledged, we found that managing for it can entail substantial trade-offs for individual landowners. To balance these trade-offs, several interviewees have found governmental incentive programs and long-term personal relationships to be successful policy instruments, in some situations, for persuading private landowners to manage for oak; thus, they called for greater funds to be allocated towards providing support for private lands management. However, state and federal natural resource budgets are limited and new funding for oak restoration is unlikely. Given this constraint, interviewees remarked on the need for oak-specific incentive programs. To accommodate these requests, resources could be shifted away from support for other forest types (i.e., sugar maple) to oak management. Such a shift would require clear valuation by society of the goods and services provided by oak forests above other forest types. This may be unlikely given that the natural resource and forestry professionals in our study have found that many private landowners are willing to accept substitutes for oak given prevailing trade-offs—as noted by an interviewee, they "learn to love maple." We suggest a need for greater understanding and discussion of the full suite of services, including non-monetary attributes, that oak provides society as compared to alternative forest types (Daily et al. 2000), thereby providing society with comprehensive information for making informed choices on the allocation of funds for managing private forestland.

If society chooses to devote resources towards oak restoration, there are a variety of policy instruments that can alter individual and collective behavior, each with specific target populations, objectives, and associated limitations (Schneider & Ingram 1990). In our project, the policy instruments identified by interviewees as sometimes valuable for restoring oak—economic incentives and personal landowner assistance—were also found as having limited success given prevailing landowner preferences and social context. For example, despite the variety of cost-share assistance programs and professional advice available to most landowners, many of the interviewees believed that a substantial portion of landowners perceived the outcomes of oak restoration practices, specifically clearcutting, as an insurmountable "cost"; one that is aesthetically objectionable and conflicts with their recreational opportunities. Bliss (2000, p. 4) explored the negative societal perceptions of clearcutting and noted that, "forest practices will not be acceptable unless they are compatible with prevailing beliefs and values." Furthermore, our findings suggest that the strong negative perceptions of oak restoration practices are amplified by forest parcelization and residential development, thereby further dissuading landowners from adopting restoration practices, namely harvesting mature trees to provide adequate light for oak establishment. Trends in forest parcelization and exurban sprawl are of increasing concern across many regions of the U.S. (Sampson & DeCoster 2000; Theobald 2005), including the Midwest (Gobster & Rickenbach 2004). In conjunction with joining the call for land use policies that could slow the rate of parcelization (Gobster & Rickenbach 2004) and sprawl (Radeloff et al. 2005), we suggest the need to design oak restoration practices that can be successfully accomplished on small parcels and provide immediate and long-term outcomes that are consistent with landowner values (Hull et al. 2004). Also, as noted by several of the professionals we interviewed, cross-boundary cooperation could be used to decrease economic constraints associated with conducting harvesting practices on small parcels and provide other non-economic benefits to private landowners (Gass et al. 2006).

As one interviewee most aptly noted, you have to "pick your battles." It is unlikely that various policy mechanisms will be able to gain the attention of all landowners in a region, especially given forest parcelization and the growing challenge this presents extension and outreach efforts (Kittredge 2004). Thus, an ecologically- and socially-focused strategy may improve the likelihood for regional oak regeneration success. A targeted approach would require a spatially explicit understanding of the ecological and social potential for oak restoration. Conservation biologists and ecologists emphasize the importance of collaborative, interdisciplinary, and synthetic efforts aimed at wedding ecological and social understanding of conservation and restoration issues (e.g., Daily & Ehrlich 1999; Balmford & Cowling 2006; Hobbs 2007). However, in areas which are predominately privately owned, site-specific information can be a challenge to obtain (Hilty & Merenlender 2003). The targeted approach outlined by our interviewees requires greater data sharing and collaboration among researchers, conservation and natural resource agencies, and private landowners. Economic resources will need to be devoted to capturing, managing, and disseminating data sources and analytical tools.

CONCLUSIONS

The fate of oak and oak-associated flora and fauna in the midwestern U.S. is emblematic of the choice faced by ecologists, managers, and society related to all ecosystems that require periodic disturbance (Litvaitis 1993; Motzkin & Foster 2002). One professional, in discussing oak, identified the compelling question facing the retention of such ecosystems and the immediacy for action: "In my opinion, the oak resource . . . is . . . at a crossroads, where we can try and be more proactive about saying, 'This is an important resource and we're going to manage for it, and we're going to take care of it.'" Unless actively managed for, early-to-mid successional vegetation types will soon be replaced by later successional forests (Nowacki & Abrams 2008), and future restoration efforts will need to rely on seeding and planting strategies that are often very expensive. As a result, options for restoring these systems will be more limited in the future than at present. We suggest that immediate discourse needs to occur to assess the acceptance of potential alternatives for oak systems, as well as for other ecosystem types facing similar peril.

IMPLICATIONS FOR PRACTICE

If oak is sufficiently valued, steps can be taken towards ensuring the future of oak and related biodiversity. These steps can be adapted to other regions in similar ecological, social, and ownership context. They include:

- Implement policy tools that specifically support appropriate restoration behavior for a particular habitat or community type.
- Develop alternative restoration practices that are considered socially appropriate given current landowner values and small parcel sizes.
- Design policy mechanisms that encourage cross-boundary cooperation.
- Envision and enact spatially-targeted policies encouraging restoration in areas that optimize ecological and social opportunities.

ACKNOWLEDGEMENTS

We sincerely thank the research participants for sharing their experiences. Project guidance and insightful review comments were provided by R. Atwell, B. Danielson, N. Grudens-Schuck, L. Merrick, J. Miller, B. Palik, A. Pierce, and J. Tyndall. C. Eberle, B. Jan, A. MacDonald, K. Smith, and M. Boyd participated in transcribing interviews. We received funding from the USDA Forest Service – Northern Research Station and Iowa State University. T. Knoot was a research fellow with the U.S. EPA – STAR Graduate Fellowship Program. EPA has not officially endorsed this publication and the views expressed herein may not reflect the views of EPA.

LITERATURE CITED

Abrams, M. D. 1992. Fire and the development of oak forests. Bioscience **42**:346-353.

Abrams, M. D., and G. J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. Bulletin of the Torrey Botanical Club **119**:19-28.

Albert, D. A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. Gen. Tech. Rep. NC-178. USDA Forest Service, St. Paul, Minnesota.

Balmford, A., and R. M. Cowling. 2006. Fusion or failure? The future of conservation biology. Conservation Biology **20**:692-695.

Baughman, M. J., and R. D. Jacobs. 1992. Woodland owners' guide to oak management. Pub-FO-05938. Minnesota Extension Service, University of Minnesota, St. Paul, Minnesota.

Bean, M. J., and D. S. Wilcove. 1997. The private-land problem. Conservation Biology **11**:1-2.

Bliss, J. C. 2000. Public perceptions of clearcutting. Journal of Forestry **98**:4-9.

Bliss, J. C., and A. J. Martin. 1989. Identifying NIPF management motivations with qualitative methods. Forest Science **35**:601-622.

Butler, B. J., and E. C. Leatherberry. 2004. America's family forest owners. Journal of Forestry **102**:4-9.

Carpenter, S. R., R. DeFries, T. Dietz, H. A. Mooney, S. Polasky, W. V. Reid, and R. J. Scholes. 2006. Millennium ecosystem assessment: research needs. Science **314**:257-258.

Crow T. R., G. E. Host, and D. J. Mladenoff. 1999. Ownership and ecosystem as sources of spatial heterogeneity in a forested landscape, Wisconsin, USA. Landscape Ecology **14**:449-463.

Daily, G. C., and P. R. Ehrlich. 1999. Managing Earth's ecosystems: an interdisciplinary challenge. Ecosystems **2**:277-280.

Daily, G.C., T. Söederqvist, S. Aniyar, K. Arrow, P. Dasgupta, P. R. Ehrlich, C. Folke, A-M. Jansson, B-O. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K-G. Mäler, D. Simpson, D. Starrett, D. Tilman, and B. Walker. 2000. The value of nature and the nature of value. Science **289**:395-396.

Esterberg, K. G. 2002. Qualitative Methods in Social Research. McGraw-Hill, Boston.

Fralish, J. S. 2004. The keystone role of oak and hickory in the central hardwood forest. Pages 78-87 in M.A. Spetich, editor. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. USDA Forest Service, Asheville, North Carolina.

Fralish, J. S., F. B. Crooks, J. L. Chambers, and F. M. Harty. 1991. Comparison of presettlement, second-growth and old-growth forest on six site types in the Illinois Shawnee Hills. American Midland Naturalist **125**:294-309.

Gass, R. J., M. Rickenbach, L. A. Schulte. 2006. Forest management on parcelized landscapes: private forest owners assessments of cross-boundary alternatives. Pages 93-102 in S. Walls, editor. Proceedings from the IUFRO 3.08 Small-scale Forestry and Rural Development Conference, Galway, Ireland, 18-23 June 2006.

Gobster, P. H., and M. G. Rickenbach. 2004. Private forestland parcelization and development in Wisconsin's Northwoods: Perceptions of resource-oriented stakeholders. Landscape and Urban Planning **69**:165-182.

Hilty, J., and A. M. Merenlender. 2003. Studying biodiversity on private lands. Conservation Biology **17**:132-137.

Hobbs, R. J. 2007. Setting effective and realistic restoration goals: key directions for research. Restoration Ecology **15**:354-357.

Hull, R. B., D. P. Robertson, and G. J. Buhyoff. 2004. "Boutique" forestry: new forest practices in urbanizing landscapes. Journal of Forestry **102**:14-19.

Iowa Department of Natural Resources, Forest Stewardship Spatial Analysis Project, 2005. URL http://www.fs.fed.us/na/sap/products/ia.shtml [accessed February 2008].

Johnson, P. S., S. R. Shifley, and R. Rogers. 2002. The ecology and silviculture of oaks. CABI Publishing, New York.

Kittredge, D. B. 2004. Extension/outreach implications for America's family forest owners. Journal of Forestry **102**:15-18.

Kittredge, D. B. 2005. The cooperation of private forest owners on scales larger than one individual property: international examples and potential application in the United States. Forest Policy and Economics **7**:671-688.

Knight, R. L. 1999. Private lands: the neglected geography. Conservation Biology **13**:223-224.

Litvaitis, J. A. 1993. Response of early successional vertebrates to historic changes in land use. Conservation Biology **7**:866-873.

McShea, W. J., and W. M. Healy. 2002. Oaks and acorns as a foundation for ecosystem management. Pages 1-9 in W. J. McShea and W. M. Healy, editors. Oak forest ecosystems: Ecology and management for wildlife. The Johns Hopkins University Press, Baltimore, Maryland.

Miller, J. R., and R. J. Hobbs. 2007. Habitat restoration—do we know what we're doing? Restoration Ecology **15**:382-390.

Motzkin, G., and D. R. Foster. 2002. Grasslands, heathlands and shrublands in coastal New England: historical interpretations and approaches to conservation. Journal of Biogeography **29**:1569-1590.

Neuman, W. L. 2003. Social research methods: qualitative and quantitative approaches. Allyn & Bacon, Boston.

Nowacki, G. J., and M. D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. Bioscience **58**:123-138.

Nowacki, G. J., M. D. Abrams, and C. G. Lorimer. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. Forest Science **36**:276-292.

Prior, J. C. 1991. Landforms of Iowa. University of Iowa Press, Iowa City, Iowa.

QSR International. 2006. NVivo 7. QSR International, Victoria, Australia.

Radeloff, V. C., R. B. Hammer, and S. I. Stewart. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and its relation to forest fragmentation. Conservation Biology **19**:793-805.

Rickenbach, M. G., and A. S. Reed. 2002. Cross-boundary cooperation in a watershed context: the sentiments of private forest landowners. Environmental Management **30**:584-594.

Rizzo, D. M., and M. Garbelotto. 2003. Sudden oak death: endangering California and Oregon forest ecosystems. Frontiers in Ecology and the Environment **1**:197-204.

Robinson, J. G. 2006. Conservation Biology and real-world conservation. Conservation Biology **20**:658-669.

Rodewald A. D., and M. D. Abrams. 2002. Floristics and Avian Community Structure: Implications for Regional Changes in Eastern Forest Composition. Forest Science **48**:267-272.

Rooney, T. P., and D. M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. Forest Ecology and Management **181**:165-176.

Sampson, N., and L. DeCoster. 2000. Forest fragmentation: implications for sustainable private forests. Journal of Forestry **98**:4-8.

Schneider, A., and H. Ingram. 1990. Behavioral assumptions of policy tools. Journal of Politics **52**:510-529.

Taylor, S. O., and C. G. Lorimer. 2003. Loss of oak dominance in dry-mesic deciduous forests predicted by gap capture methods. Plant Ecology **167**:71-88.

Theobald, D. M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society **10**:32. URL http://www.ecologyandsociety.org/vol10/iss1/art32/ [accessed February 2008].

USDA Forest Service, Forest Inventory and Analysis Data Base Retrieval System, 2005. URL http://ncrs2.fs.fed.us/4801/fiadb/fim17/wcfim17.asp [accessed February 2008].

West P. C., J. M. Fly, D. J. Blahna, and E. M. Carpenter. 1988. The communication and diffusion of NIPF management strategies. Northern Journal of Applied Forestry **5**:265-270.

Wisconsin Department of Natural Resources. 2005. Wisconsin’s strategy for wildlife species of greatest conservation need. Pub-ER-641. Madison, Wisconsin.

CHAPTER 3.
THE CHANGING SOCIAL LANDSCAPE IN THE MIDWEST: A BOON FOR FORESTRY AND BUST FOR OAK?

A paper submitted to *Journal of Forestry*

Tricia G. Knoot, Lisa A. Schulte, Nancy Grudens-Schuck, and Mark Rickenbach

ABSTRACT

Recent forest surveys report poor oak regeneration on the privately-held forestlands of the Midwest. Data from in-depth interviews with natural resource and forestry professionals from the region suggested that changing ownership patterns, increasing property values, widespread forest parcelization, and exurban residential development, both directly and indirectly limit the likelihood of oak regeneration. Foremost, interviewees noted that typical practices used to regenerate oak, such as clearcutting, were often viewed by landowners as incompatible with expectations of how forestland should be experienced under their care. Such constraints may be countered by the observation that new family forest owners are more economically able to engage in sustainable forestry practices and are highly motivated to manage their forests as compared to owners of the past. Interviewees provided a multifaceted portrait of new opportunities for engaging private landowners in sustainable forestry management but posed a questionable future for oak.

INTRODUCTION

Changing land tenure and structure of ownership patterns, including forest parcelization and shifting landowner demographics, have ignited concerns that sustainable forestry is generally untenable on private forestlands throughout the United States. Natural resource and forestry professionals experience firsthand the changing social landscape, as many are charged with offering knowledge and advice to a growing number of private landowners (Kittredge 2004). The majority of these new owners have been found to value their woodlands less for timber than for aesthetics and land investment (e.g., Butler and Leatherberry 2004, Kendra and Hull 2005)—priorities that may not require active and sustainable forest management (Erickson et al. 2002). In many forested systems, periodic disturbance (e.g., fire) promotes the establishment and dominance of key forest types throughout the U.S., such as the dry ponderosa pine (*Pinus ponderosa*) and mixed conifer forests of the Inland Northwest

(Hessburg et al. 2005), longleaf pine (*Pinus palustris*) ecosystems in the southeastern U.S. (Platt et al. 1988), and oak (*Quercus* spp.) forests of the midwestern and eastern U.S. (Nowacki and Abrams 2008). To maintain and restore disturbance-dependent forest types and associated biodiversity, a variety of management techniques, including tree removal and prescribed fire, can be used to shape forest structure, thereby mimicking the outcomes of historic disturbance regimes (Franklin et al. 2002, Palik et al. 2002). However, predominant forestry practices may be unworkable given smaller parcel sizes, and may be incongruent with the current values, knowledge, beliefs, or management objectives of landowners (e.g., DeCoster 1998, Bliss 2000, Kendra and Hull 2005). Because changing ownership patterns appear to suggest that fewer private lands are sustainably, or even actively, managed (Sampson and DeCoster 2000), future access to associated ecosystem goods and services provided by privately owned forests (e.g., timber, biodiversity)—especially disturbance-dependent forest types—is at risk.

Oak forests of the midwestern and eastern U.S. figure prominently in this dilemma. Oak forests are considered vital habitat for maintaining biodiversity, having provided stable, suitable habitat for a wide variety of wildlife and plant species for thousands of years (Fralish 2004). Oaks of various species are considered early to mid-successional species, require adequate light for recruitment, are relatively resilient to fire, and readily stump sprout. These attributes usually allow oaks a competitive advantage when a site is periodically disturbed by natural or human-caused events (Johnson et al. 2002). Historically, the occurrence of both natural and anthropogenic fires before and at the time of Euro-American settlement promoted oak establishment. However, fire is largely absent from current forest stands in the midwestern and eastern U.S. Consequently, later successional tree species, such as sugar maple (*Acer saccharum*) and American basswood (*Tilia americana*) have flourished in the understory of mature oak forests, indicating the potential for replacement of oak-dominated forests (Nowacki and Abrams 2008).

Because the majority of oak-dominated forests in the midwestern U.S. are in private ownership (USDA Forest Service 2005), current land management decisions by private landowners may be predicted to substantially influence the trajectory of forest change, thus the long-term future of valuable oak-associated resources. Although natural resource agencies in the Midwest have listed oak management as a top priority (Iowa Department of Natural Resources 2005, Wisconsin Department of Natural Resources 2005), meeting this objective would require widespread, active, and even intensive forest management by private landowners. For example, oak management and regeneration practices typically include harvesting a substantial proportion of the forest overstory through such methods as clearcutting, shelterwood, and group selection techniques (Johnson et al. 2002). The repeat removal of understory plant competitors manually, or through the use of herbicides and/or prescribed fire, enhance efforts to improve the competitiveness of young oak (Johnson et al. 2002). Current oak management prescriptions, therefore, call for landowners to harvest at least some mature trees and to commit substantial time and resources to improve oak establishment prior to and/or following a harvest. While the general public typically holds negative perceptions of clearcutting practices (Bliss 2000), it is unclear how changing ownership patterns (e.g., landowner management priorities, forest parcelization) might influence widespread oak regeneration success in a landscape composed of diverse and numerous private landowners. By looking carefully at the new social realities of maintaining and restoring oak, we may be able to illuminate mechanisms for successfully ensuring that the goods and services that society demands from disturbance-dependent ecosystems are delivered regionally over time. In this paper, we identify constraints and opportunities that changing ownership patterns present to natural resource and forestry professionals seeking to encourage sustainable forest management—especially of disturbance-dependent ecosystems—by examining the phenomenon of oak regeneration on privately-owned lands.

METHODS

We chose the Driftless Area of the Midwest, also known as the Paleozoic Plateau or Blufflands, as our study region (Figure 1). Forests make up about one-third of the landcover. Oak-hickory and maple-basswood forests are the dominant forest types, representing 54% and 23% of the forest cover, respectively (USDA Forest Service 2005). Forestland, 90% of which is in private ownership (USDA Forest Service 2005), is an essential part of the working landscape in the Driftless Area, providing abundant goods and services, including wildlife habitat (Pusateri et al. 1993), soil stabilization (Knox 2001), timber production (Jacobs and Wray 1992), and recreation.

We used a qualitative research framework to provide depth of understanding of regional natural resource and forestry professionals' experiences working with private landowners in this changing social-ecological landscape. Qualitative inquiry can provide fundamental insights when little is known about a topic (Strauss and Corbin 1990). It was an appropriate approach for our research given the paucity of information on landowner engagement with natural resource and forestry professionals towards achieving oak regeneration goals. The lead author conducted in-depth, semi-structured, interviews with 32 natural resource and forestry professionals from October 2005 to May 2006. Additional sources for data included participant observation while in attendance at professional meetings and follow-up phone and personal visits with interviewees and others. Potential participants were identified through a non-random selection process, described as purposive ("snowball" sampling), in which subsequent participants were identified by preceding interviewees (Esterberg 2002), with an eye toward increasing diversity of points of view. Consequently, the selection pool featured professionals with a substantial amount of experience and with potentially diverse perspectives—attributes important to high-quality inquiry of this type. In summary, 84% of the interviewees had worked as a natural resource or forestry professional for at least 10 years and over half of the participants had at least 20 years of experience. The interviewees had regular contact with private landowners and possessed various technical natural resource knowledge backgrounds. The pool consisted of publicly-employed foresters (n=13), other publicly-employed natural resource or forestry specialists (e.g., forestry extension specialists; n=5), privately-employed forestry professionals (e.g., consulting foresters; n=8), and those employed by the timber industry (e.g., sawmill owners and loggers; n=6).

Seventeen of the interviews were conducted in person and the remaining interviews were conducted by telephone; interviews were digitally recorded. Interviews averaged 49 minutes, and ranged between 23 and 107 minutes in length. Indicative of semi-structured interviews, each interview followed a similar question format, but the successive questions (probes, clarifications, additional topics) were guided by the participant's responses; therefore, each interview was unique (Esterberg 2002). The transcribed text from the interviews was coded and themes were developed using an "open coding" process that required categorizing sections of transcribed text (Esterberg 2002) with the aid of NVivo 7qualitative analysis software (QSR International 2006). Codes were then used to develop themes and categories of themes; i.e., recurring sentiments by interviewees. The percentages listed in our findings that follow represent the proportion of interviewees that shared a similar experience or sentiment, coded as a theme or thematic category, in response to our questions. However, consistent with qualitative inquiry, "minority" or infrequently-mentioned ideas and perspectives were also important to constructing the findings (Strauss and Corbin 1990). The paper provides quotations from interviews to illustrate key findings. Participants were assigned pseudonyms as part of a larger process of providing confidentiality per a university-based institutional review process designed to protect the rights of human subjects.

FINDINGS AND DISCUSSION

Interviewees readily spoke of widespread changing ownership patterns, including a decrease in farmer-owned forestland and concomitant increase in non-farmer and absentee landowners. As an example, in response to a question regarding the most noticeable changes to the landscape and/or the forest resources, Grant, a public forester for nearly 30 years, noted, "I would guess that 80% of the people I worked with 20 some years ago were farming. Now, I think that's completely flopped. I'd say that 80% of the people we work with are [non-farmer] professional people." Table 1 highlights the most frequently cited changes in ownership including an increase in forestland property value; widespread forest parcelization; residential development; high overturn of land ownership; and an increase in landowners that purchased woodlands for non-timber purposes such as recreation, privacy, aesthetics, and as part of a residence. The interviews illustrated a variety of challenges and associated concerns related to changing ownership patterns, resulting in the first thematic category: *ownership changes challenge sustainable management*. A second theme, however, featured an unanticipated opportunity for the forestry profession: *new landowners as engaged land stewards*. In addition, the interviewees noted specific implications of the changing social landscape to oak management as exemplified by a third and fourth categories: *incongruent landowner needs and oak management outcomes*, and *incomplete landowner knowledge about oak regeneration*.

Theme #1: Ownership Changes Challenge Sustainable Management. The natural resource and forestry professionals expressed concerns about the effects of changing ownership patterns on forest resources and the forestry profession in general (Table 1). Many of these perspectives have been voiced in the forestry literature, including operational constraints of managing small forest parcels, landowner's non-consumptive priorities for forestland, and increasing residential development in forested areas that were once contiguous (e.g., DeCoster 1998, Kittredge 2004, Radeloff et al. 2005). Interviewees however provided a nuanced and sophisticated analysis of both the local and regional situation. Notably, forest professionals discussed changing ownership patterns as a suite of factors which exhibited relationships across scales and over time. For example, forest parcelization and exurban residential development were typically treated as a sequence of events, with the former preceding the latter, with a suggestion of causation. In addition, interviewees often related changes in macro-level factors (e.g., exurban residential development) with changes in the characteristics of individual landowners (e.g., landowner management priorities). One interviewee suggested that due to an increase in the demand for exurban residential housing, landowners have been willing to pay an amount that exceeded the timber value of a forested property—making sustainable long-term timber management of little or no importance to some individual landowners. Several interviewees also postulated a connection between exurban residential development and a decrease in active forest management, noting that private landowners that lived on their forested parcels were in regular and direct contact with their property, therefore were less likely to manage the forest in ways that conflicted with their aesthetic appreciation of the landscape. In addition, operational constraints associated with small parcels and exurban residential development were found by some interviewees to decrease the likelihood of active forest management.

The proposed changes in landowner priorities away from consumptive uses, parcelization, and exurban development have long concerned those in the forestry community. While our findings are restricted to the experiences of a relatively small number of professionals, the interviewees' claims are duplicated and substantiated through other interdisciplinary research efforts aimed at understanding landscape change in the midwestern U.S. (see Gobster and Haight 2004). Related to oak, Gobster and Haight (2004) found that housing density influences timber harvesting activities; roughly 80% of oak-hickory harvests occurred in areas with lower housing density (less than about 20 houses/km^2). The present study's findings, in conjunction with the results from Gobster and Haight (2004), suggest that continued parcelization and exurban residential development—excluding the associated clearing of trees for housing development—will decrease timber harvesting, limiting the use of this important tool for perpetuating disturbance-dependent, early to mid-successional, forest types such as oak.

These challenges and concerns documented in the forestry literature from around the nation strengthened the call to identify workable policies that address macro-level changes and provide support for natural resource and forestry professionals. The study suggests the need for (1) changing land use policies; i.e., "smart growth" directed toward slowing forest parcelization and exurban residential development (Sampson and DeCoster 2000); (2) developing communication, educational, and outreach tools to attract new landowners to acquire forest management skills and behaviors (Butler et al. 2007); and (3) developing forestry practices that are more consistent (or conflict less) with landowner needs and desires, and which are applicable to smaller parcels (DeCoster 1998).

Theme #2: New Landowners as Engaged Land Stewards. Leo, a consulting forester for over 20 years remarked,

> If a guy from Minneapolis has money to invest in just buying land to play, then what we're finding . . . they end up being our best clients because then they have money to invest, to not only improve the wildlife, but [the landowner will say], "I'd really like to do some forest management," and they're willing to spend money on it. . . . In my view, it's probably beneficial from a forestry standpoint.

While most of the interviewees expressed concerns regarding changing ownership patterns, the majority of interviewees also provided examples of ways in which changing ownership patterns benefited forests and improved relations between forestry professionals and private landowners. Many noted that increased numbers from among the new set of landowners displayed positive land stewardship attitudes and behaviors. The interviewees also noted the overall improved socioeconomic status of new landowners and greater willingness of current landowners to engage with natural resource and forestry professionals. With optimism and a sense of relief, nearly 20 percent of those interviewed remarked that as land changed hands, the new landowners have expressed more interest and have shown to be highly motivated in seeking professional advice as compared to farm owners of the past. Thus, while frequent ownership changes pose challenges, our findings suggest that these same changes offer enhanced opportunities for forestry professionals to provide information and guidance on forest management—the vital first step towards sustainable management of private forestland. As Truman, a public forester for over 20 years, noted,

> A lot of times when somebody purchases a parcel . . . they know that things should be done, but they don't know what they are, and they come looking for some information from a resource professional, whether it is a forester, or they get a hold of a wildlife manager or somebody. So that is a plus that people are owning the land and they know that they don't know what to do. . . . That's one benefit . . . there's some active management going on out on the land that wasn't there in the past.

That said, while an increase in new landowners may result in more inquiries, active forest management requires a landowner to take steps beyond showing interest. Management costs both time and money. Successful sustainable forest management involves short-term and sometimes repeat investment of economic resources to support such practices as timber stand improvement. Landowners typically gain few economic benefits from these practices in the short term, if ever; hence, a higher economic status of a landowner likely influences the success of their engagement in forest management (Beach et al. 2005). Forty-one percent of interviewees viewed traditional farm owners as too economically constrained to engage in sustainable forest management activities, such as timber stand improvement, whereas they have found new landowners to be more willing and able to devote both time and money to land management, although certainly not all are in this category. Dale, a private logger and contract forester for over 30 years, remarked,

> I know we used to cut for jobs so [a farmer] could make a bank payment to keep their farm. There would be a lot of raping and pillaging and cutting stuff that should not have been cut. But they were looking to keep swimming. Where the new [landowners] . . . they pay $3,000 an acre for land. I don't even own any land. I can't afford it. But to them [forest management] is no big deal.

In addition to Dale, several other interviewees perceived a greater opportunity for active forest management on private lands when paired with higher property values. Some participants also viewed higher property values as related to a shift away from landowner interest in solely the timber value of their land, regarded earlier as a constraint (Table 1). However, this same change was discussed as an opportunity for pushing the profession to become more learned and active in helping people to set and achieve diverse natural resource goals. Grant, a public forester for nearly 30 years, remarked,

> These [new landowners], the reason they bought [the land] was the woods, and so they're concerned about everything there. There's some resistance to herbicides, because they tend to be people that are really environmentally conscious; they don't want to do anything that messes up the woods. So, it's made us . . . be broader focused.

As reflected in Grant's statement, the majority (78%) of participants found that some new landowners have greater land stewardship knowledge, ethics, and environmental concerns than previous landowners. Sam, a publicly-employed forestry professional for eight years, remarked about this same phenomenon, "Our new landowners . . . they're interested in sustainability, and longevity, and providing forest resource for the generation to come too, which is good to see and work with."

Consistent with the experiences of our interviewees, several studies of private landowner characteristics have provided evidence that a segment of new landowners appreciate the ecological amenities of their forests and have the economic means and interest in forest management for reasons such as improving habitat for wildlife (e.g., Kendra and Hull 2005, Rickenbach et al. 2006). We also found through our interviews with natural resource and forestry professionals, and as described in Kendra and Hull (2005), that new landowners hold diverse backgrounds and have a wide range of motivations for owning their forests, from absentee investors to forest planners and preservationists, requiring that forestry professionals are prepared with multiple strategies for communicating to and working across the new landowner population. Moreover, as experienced first hand by the study participants, new landowners may be eager and willing to work directly with natural resource and forestry professionals if the professionals can communicate in ways that are meaningful to them and can design management plans that meet landowner interests.

Theme #3: Incongruent Landowner Needs and Oak Management Outcomes. As Ed, a public forester for over 30 years, exclaimed, "So when we're trying to regenerate oak by clear cutting . . . [the landowners] just go, 'You're doing what?!' . . . You can't make people like a field of stumps." Despite the potential opportunities for sustainable forest management afforded by changes in land ownership, widespread oak-specific management may remain inadequate because the current set of management practices is unpalatable to many landowners. For example, landowners were viewed by 81 percent of the professionals as appreciating their forestland primarily for the attributes afforded by mature trees, such as aesthetics, recreation, and privacy. Harvesting a substantial portion of the forest overstory to allow adequate light for oak recruitment conflicts with this priority. Tim, a public forester for over 10 years, noted,

> They don't want to see clearcutting. They don't want to see a shelterwood, which usually ends in something that looks like a clearcut. They don't want to do the heavy cutting that it would take to create the light needs for an oak. They like their trees. They're OK with harvesting, but this real light, selective harvesting. It is an aesthetic thing.

While new landowners may be more willing and able to engage in forest management, most of the natural resource and forest professionals have found that landowners were more interested in low-impact activities that were not necessarily conducive to oak regeneration. Instead, favored management strategies often encouraged the growth of later-successional tree species, such as sugar maple. To explain these landowner management preferences, several interviewees noted that forest parcelization and residential development often resulted in more landowners who were in frequent and direct contact with their forested property. When harvesting has been used to regenerate oak, interviewees noted the unappealing appearance of the site immediately, and for up to a decade, post-harvest. Consequently, managing for oak on small parcels and where a landowner has built a residence was found by the professionals as often unacceptable by landowners. Rich, who has worked as a consulting forester and public forester for nearly 20 years, remarked,

> Those timbered acres are now really becoming sort of an extension of their backyard. And some of the practices that we need to regenerate oak, including clearcutting, are not very palatable to a lot of landowners. . . . They like big, old trees. . . . They're most likely to try to hang onto those big old oaks until they die.

Theme #4: Incomplete Landowner Knowledge about Oak Regeneration. Many of the interviewees have worked with landowners who were interested in managing their lands for wildlife. Indeed, managing for oak forests meets this criterion. However, landowner support for wildlife did not automatically translate into their acceptance of oak management practices. Notably, concepts such as "ecological succession" and "ecological disturbance" were not well developed among landowners. Grant remarked,

> There's a lot of pressure from . . . people that think that what we have is so neat, [so] we should not bother it, not realizing that what we have is a result of logging, grazing, fire, and disturbance. So, they want to take disturbance out of that, which is dooming [the oak] forest type. There is no way you can maintain oak without disturbance. We have to get to these people and explain to them, 'We agree with you. What we have is really neat, but this is what we're going to have to do to keep it.' The whole idea of succession doesn't click with most professions; forestry is unique. . . . Succession is what we do; we're managing succession.

Without landowner appreciation of the importance of disturbance to oak regeneration and the long term viability of wildlife habitats, professionals suggested that landowners were less likely to implement practices, such as fire and harvesting, that can favor oak.

The forestry professionals also spoke of an interesting relationship between new landowners and the large deer herds in the region—a relationship that is likely detrimental to oak regeneration (Rooney and Waller 2003). Several of the interviewees relayed stories about new private landowners valuing their land for hunting purposes, specifically deer hunting, and so were interested in attracting deer to their lands. The professionals observed that many of these landowners are unaware of, and sometimes unconcerned about, the negative impact that deer browse can have on oak regeneration. As Tim remarked,

> To start with, a lot of [new landowners] just can't see or are not aware of the damage [deer] are causing. . . . A lot of these people, the recreational buyer, they bought the

> land to hunt deer on it. . . . You tell them that there's too many deer and so it's sometimes like talking to a brick wall.

On the other hand, several interviewees found that new landowners were not generally interested in opening their forested property to public hunting, a decision that potentially contributes to larger deer herds in the region. Dale commented with dismay, "A lot of these new style landowners post [no hunting on] their land. You know, I sure don't like that. . . . They keep a pretty good deer herd in there. They lure them in there and feed them. . . . That's a pretty big concern." Although educating the landowner about the problem with deer is possible, several of the interviewees noted the perceived contentious politics among natural resource organizations regarding the large deer herds. As Phil, a sawmill owner who grew up in the region, remarked,

> The hunting groups . . . have a very strong influence on [the issue with deer] too; a stronger influence I think than the forest industry. . . . .It's a very strong economic boon, which continues to grow, which is going to make it increasingly difficult to knock that deer herd down.

Therefore, lack of knowledge as well as incomplete understandings by landowners of forest succession, the importance of disturbance and oak regeneration, and the detrimental effects of deer on oak regeneration potentially influence landowner behavior regarding land management decisions. These uninformed decisions then negatively impact oak regeneration.

CONCLUSIONS

The social acceptability of forestry practices by non professionals is crucial to maintaining and restoring disturbance-dependent forest types. While the changing social landscape in our study region presents a potential positive outlook for sustainable forest management on privately owned lands, we found that these changes painted a relatively bleak picture for the future of oak, a forest type that requires active forest management and utilizes practices that lack broad social acceptability. Natural resource and forestry professionals found it difficult to encourage landowners to adopt current oak regeneration practices, but not sustainable forestry practices in general. Oak management practices, at the current time, appear to be misaligned with the landowners' desired outcomes for their experience as owners of forests, especially landowners who chose to live in close proximity to their forestlands. Our finding that landowners may lack knowledge about ecological requirements for successful oak regeneration suggests that an informational campaign focused on the importance of disturbance to oak ecology (and attendant wildlife) may decrease resistance to specific oak management practices, such as tree removal and use of fire. However, it is unknown if improved understanding of oak regeneration would outweigh conflicts between the successful outcomes of oak management practices and landowners' desires for aesthetics and privacy. Our study points to the need to better pinpoint the most influential aspects of oak management, and management of other disturbance-dependent forest types, that inhibit landowner adoption, and develop policy mechanisms to lower these barriers. Development of technical and policy tools to account for small parcel size and fragmentation is also needed to better support options that forest and natural resources professionals may offer to new forest landowners.

ACKNOWLEDGEMENTS

We sincerely thank the research participants for sharing their experiences in depth and with great insight. Project guidance and review comments were provided by R. Atwell, B. Danielson, L. Merrick, J. Miller, B. Palik, A. Pierce, and J. Tyndall. C. Eberle, B. Jan, A. MacDonald, K. Smith, and M. Boyd participated in transcribing interviews. Funding was provided by the USDA Forest Service – Northern Research Station, and Iowa State University. T. Knoot was a research fellow with the U.S. EPA – STAR Graduate Fellowship Program. EPA has not officially endorsed this publication and the views expressed herein may not reflect the views of EPA.

LITERATURE CITED

Beach, R.H., S.K. Pattanayak, J.-C. Yang, B.C. Murray, and R.C. Abt. 2005. Econometric studies of non-industrial private forest management a review and synthesis. For. Policy Econ. 7:261-281.

Bliss, J.C. 2000. Public perceptions of clearcutting. J. For. 98(12):4-9.

Butler, B.J., and E.C. Leatherberry. 2004. America's family forest owners. J. For. 102(7):4-9.

Butler, B.J., M. Tyrrell, G. Feinberg, S. Vanmanen, L. Wiseman, and S. Wallinger. 2007. Understanding and reaching family forest owners: lessons from social marketing research. J. For. 105(7):348-357.

Decoster, L.A. 1998. The boom in forest owners—a bust for forestry? J. For. 96(5):25-28.

Erickson, D.L., R.L. Ryan, and R. De Young. 2002. Woodlots in the rural landscape: landowner motivations and management attitudes in a Michigan (USA) case study. Landsc. Urban Plan. 58:101-112.

Esterberg, K.G. 2002. *Qualitative methods in social research.* McGraw-Hill, Boston. 256 p.

Fralish, J.S. 2004. The keystone role of oak and hickory in the central hardwood forest. P. 78-87 in *Upland oak ecology symposium: history, current conditions, and sustainability*, Spetich, M.A., (ed.). USDA For. Serv. Gen. Tech. Rep. SRS-73. Asheville, North Carolina.

Franklin, J.F., T.A. Spies, R. Van Pelt, A.B. Carey, D.A. Thornburgh, D.R. Berg, D.B. Lindenmayer, M.E. Harmon, W.S. Keeton, D.C. Shaw, K. Bible, and J. Chen. 2002. Disturbance and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For. Ecol. Manag. 155:399-423.

Gobster, P.H., and R.G. Haight. 2004. *From landscapes to lots: Understanding and managing Midwestern landscape change.* USDA For. Serv. Gen. Tech. Rep. NC-245. St. Paul, Minnesota. 60 p.

Hessburg, P.F., J.K. Agee, and J.F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras. For. Ecol. Manag. 211:117-139.

Iowa Department of Natural Resources. 2005. Forest Stewardship Spatial Analysis Project. Available online at www.fs.fed.us/na/sap/products/ia.shtml; last accessed March 27, 2008.

Jacobs, R.D., and R.D. Wray. 1992. *Managing oak in the Driftless Area*. Publication number BU-05900. Minnesota Extension Service, University of Minnesota, St. Paul, Minnesota.
Johnson, P.S., S.R. Shifley, and R. Rogers. 2002. *The ecology and silviculture of oaks*. CABI Publishing, New York. 503 p.

Kendra, A., and R.B. Hull. 2005. Motivations and behaviors of new forest owners in Virginia. For. Sci. 51:142-154.

Kittredge, D.B. 2004. Extension/outreach implications for America's family forest owners. J. For. 102(7):15-18.

Knox, J.C. 2001. Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. Catena 42:193-224.

Nowacki, G.J., and M.D. Abrams. 2008. The demise of fire and “mesophication” of forests in the eastern United States. Bioscience 58:123-138.

Palik, B.J., R.J. Mitchell, and J.K. Hiers. 2002. Modeling silviculture after natural disturbance to sustain biodiversity in the longleaf pine (*Pinus palustris*) ecosystem: balancing complexity and implementation. For. Ecol. Manag. 155:347-356.

Platt, W.J., G.W. Evans, and S.L. Rathbun. 1988. The population dynamics of a long-lived conifer (*Pinus palustris*). Am. Nat. 131:491-525.

Pusateri, W.P., D.M. Roosa, and D.R. Farrar. 1993. Habitat and distribution of plants special to Iowa’s Driftless Area. *J. Iowa Acad. Sci.* 100:29-53.

QSR International. 2006. NVivo 7. QSR International, Victoria, Australia.

Radeloff, V.C., R.B. Hammer, and S.I. Stewart. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and its relation to forest fragmentation. Conserv. Biol. 19(3):793-805.

Rickenbach, M.G., R.P. Guries, and D.L. Schmoldt. 2006. Membership matters: comparing members and non-members of NIPF owner organizations in southwest Wisconsin, USA. For. Policy Econ. 8:93-103.

Rooney, T.P., and D.M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. For. Ecol. Manag. 181:165-176.

Sampson, N., and L. Decoster. 2000. Forest fragmentation: implications for sustainable private forests. J. For. 98(3):4-8.

Strauss, A., and J. Corbin. 1990. *Basics of Qualitative research: Grounded theory procedures and techniques.* Sage Publications, Newbury Park, California. 272 p.

USDA Forest Service. 2005. *Forest inventory and analysis data base retrieval system*. Available online at www.ncrs2.fs.fed.us/4801/fiadb/fim21/wcfim21.asp; last accessed Mar. 24, 2008.

Wisconsin Department of Natural Resources. 2005. *Wisconsin’s strategy for wildlife species of greatest conservation need*. Pub-ER-641. Madison, Wisconsin.

Table 1. Issues most frequently discussed by interviewees, proportion of interviewees that discussed the issue, examples of associated concerns, and quotations representative of changing ownership patterns in the Midwest Driftless Area.

Issue	Proportion of interviewees	Associated concerns	Quotation
Landowners place greater importance on non-timber attributes of forestland	81%	Fewer landowners interested in using harvesting as a management tool	Seth, a public forester for over 20 years, commented, "[Private landowners] don't like the idea of losing their trees. . . . When people buy a property and they see the big trees on it . . . they say, 'Well, I want this to look like this the entire term of my ownership.' They don't want to cut them down and hope something comes back."
Increase in forest parcelization	75%	Increase in operational constraints to manage-ment	Jake, a public forester for over 30 years, noted, "Sometimes the small acreage they have doesn't facilitate feasible harvest operation. The volume is too small unless one could coordinate several neighbors together."
Increase in the economic value of forestland	59%	More landowners value forested property for short-term, non-timber, reasons	Ed, a public forester in the region for over 30 years, remarked, "The changes in the land tenure…have tremendous implications. When it was part of a farm, and the farm stayed in your family…then you could think long term. But now it's a short term asset. If you're talking about land that's worth $3,000 to $4,000 an acre, that's way beyond what it could produce from a timber stand-point. [It] doesn't really matter how productive your forest is, [it] has more to do with real estate speculation and how long you plan to stay there than anything."
Increase in exurban residential development	59%	Fewer landowners interested in forest management activities	Grant, a public forester for nearly 30 years, commented, "Once you put houses in that area…you've probably precluded any management on that surrounding area. People are not going to be nearly as apt to do harvesting and timber stand improvement when their house is sitting right there."
More absentee landowners	50%	Landowners less familiar with and knowledgeable about their forestland	Jake, a public forester for over 30 years with nearly 20 years in the Driftless Area, commented, "Over time there has been an increasing number of non-resident owners, a lot of which are not very well connected to the land…I think there's a fair number of misperceptions about the reality of what forestry is about. . . . You get some [landowners] that believe that if you leave a forest alone, that's the best thing."
More frequent ownership changes	31%	Increase in non-sustainable harvests	Tim, a public forester for over 10 years, noted, "I'm seeing a lot of turnover with land. If [forested property] is changing hands every ten years, then there's always pressure [to harvest] every time it changes. It's hard to really grow a sustainable forest. [Landowners] are just going to keep depleting them."

Figure 1. The Midwest Driftless Area of the U.S. is roughly 12.4 million acres in size and covers portions of southeastern Minnesota, southwestern Wisconsin, northeastern Iowa, and a small area in northwestern Illinois.

CHAPTER 4.
THE STATE, RESILIENCE, AND POTENTIAL FUTURE OF MIDWESTERN U.S. OAK FORESTS AS PERCEIVED BY REGIONAL CHANGE AGENTS

A paper to be submitted to *Ecology and Society*

Tricia G. Knoot, Lisa A. Schulte, John Tyndall, and Brian Palik

ABSTRACT

Current ecological, economic, and social conditions present unique challenges to natural resource managers seeking to maintain the resilience of disturbance-dependent forest ecosystems, particularly in tightly coupled human and natural forest systems where the relationship between humans and the environment is continually changing. Oak-dominated ecosystems throughout the U.S. have historically been perpetuated through periodic disturbance, such as fire, but more recently show decline given shifting disturbance regimes associated with human land management decisions. We characterized the current state, resilience, and potential future of oak-dominated forests in the midwestern U.S. through the perspectives of 32 natural resource professionals. Data from interviews with these change agents provided in-depth understanding of key system components, cross-scale interactions, dependencies, and feedbacks. Foremost, private landowner management decisions figured prominently in influencing oak regeneration success and were directly and indirectly shaped by a suite of interdependent ecological (e.g., deer herbivory, invasive shrub occurrence), economic (e.g., the cost of oak regeneration practices, the stumpage value of maple as compared to oak), and social (e.g., forestland parcelization, and personal relationships) forces. Interviewees envisioned, and often preferred, a decline in oak dominance throughout the region, pointing to issues related to general landowner unwillingness to restore oak, the current trajectory of forest change, and a combination of ecological and social factors that decrease the economic feasibility of restoration efforts. The current ecological and social trends associated with this preferred future, however, may result in ecological communities that have no compositional equivalent on record and may not offer a desirable endpoint (e.g., shrubland). Thus, dialogue among stakeholder groups is needed to envision alternative

preferred system states and create workable solutions that can prevent the loss of valued ecosystem goods and services due to shifts toward undesirable systems.

INTRODUCTION

In many regions of the United States, the present extent and composition of forests are substantially different than during the time period prior to Euro-American settlement (Schulte et al. 2007, Nowacki and Abrams 2008), due in part to human land management decisions that have directly and indirectly altered the pattern of disturbance on the landscape. Presettlement disturbance regimes, influenced by a combination of biophysical conditions, ecological processes, and land management decisions by American Indians (Delcourt and Delcourt 1997), created a heterogeneous landscape composed of a variety of forest types of various ages (Abrams 1992, Radeloff et al. 2000, Drever et al. 2006, Schulte et al. 2007). In many regions of the U.S., disturbance-dependent, early- to mid-successional forest types once contributed to landscape heterogeneity, thriving in areas that experienced periodic disturbance, such as fire. More recently, many of these forests have experienced declining regeneration due to more recent land management decisions (e.g., fire suppression, selective harvesting). Examples of such ecosystems include the dry ponderosa pine (*Pinus ponderosa*) and mixed conifer forests of the Inland Northwest (Hessburg et al. 2005), longleaf pine (*Pinus palustris*) forests of the Southeast (Platt et al. 1988), mixed-pine ecosystems of the Great Lakes Region (Palik and Pregitzer 1992), and the oak (*Quercus* spp.)-dominated forests of the eastern and midwestern U.S. (Nowacki and Abrams 2008).

Ecosystem resilience is described as the ability of an ecosystem to adapt to perturbations and to change or recover in such a way that maintains function, structure, identity, and feedbacks (Holling 1973, Walker et al. 2004). In the context of disturbance-dependent forest types, such as those described above, managing for ecosystem resilience requires appropriate management prescriptions that create conditions mimicking the outcomes of historic disturbance regimes (Franklin et al. 2002, Palik et al. 2002, Drever et al. 2006). However, changes in ecosystem composition and structure since Euro-American settlement, in combination with widespread landscape fragmentation and increasing complexity of land ownership patterns, have created ecological and social conditions that make the re-establishment of historic disturbance regimes unlikely without purposeful and informed intervention (Cissel et al. 1999, Suding et al. 2004, Abrams 2005). For example, clearcutting (the removal of most overstory trees during a single regeneration harvest) can be useful for regenerating early- to mid-successional forest types, such as the oak-hickory forests of the eastern and midwestern U.S. (Johnson et al. 2002), but is often viewed by society as having objectionable outcomes. The social acceptability of such practices is crucial to the success of forest management (Bliss 2000), given that the majority of forestland in the U.S. is in private ownership (Butler and Leatherberry 2004). For this reason, policy makers and managers seeking to increase the resilience of disturbance-dependent forest types must thoroughly understand both ecological and social features of the system, and work to develop policies and management practices that are ecologically effective, socially acceptable, and enhance ecosystem resilience.

Traditional approaches to understanding and managing natural resources within coupled human and natural systems (hereafter termed social-ecological systems; Gunderson and Holling 2002) have been sometimes ineffective or detrimental to ecosystem sustainability and resilience (Holling and Meffee 1996). In particular, research and management frameworks seeking optimal solutions have typically relied on linear predictive models and command-and-control methodologies. These approaches often fail to appreciate several important features of social-ecological systems, including the influence of cross-scale interactions, multiple stakeholder interests and perspectives, and the unpredictability of human behavior and decision making (Holling and Meffe 1996, Walker et al. 2002, Cumming et al. 2006).

In response to some of the failings of traditional approaches to natural resource management, innovative research and management frameworks have been developed to understand and manage the resilience of social-ecological systems. Such resilience-based approaches include systems modeling and analysis (Allison and Hobbs 2006), alternative scenario development (Chapin et al. 2003, Peterson et al. 2003b), and stakeholder participation (Walker et al. 2002). In particular, Walker et al. (2002) propose a working hypothesis of a novel and integrative research approach, described as resilience analysis and management, which utilizes all three methods. One of the main goals of their approach is to develop creative pathways to the future. In the process, they illuminate the biophysical and social aspects of the system, cross-scale interactions, and possible management actions and policy mechanisms that can contribute to building system resilience. Walker et al (2002) present four critical steps in their approach and identify the main expected products from each step. Specifically, the authors note that the first step in the process produces a stakeholder-driven conceptual model of the system and bounds the problem by identifying the salient processes, actors, drivers, and uncertainties. It explores the historical context from which the system developed, essentially identifying the resilience "of what." This step provides the critical elements for identifying a set of possible future scenarios or trajectories of change in the system—step two in their approach. Steps three and four, respectively, include a qualitative and quantitative assessment of resilience and stakeholder evaluation.

We adapted the resilience analysis and management framework, specifically steps one and two, to explore the state, resilience, and potential future of oak-dominated ecosystems in the midwestern U.S. Forest ecologists from the eastern and midwestern U.S. suggest that oaks have been an important component of the landscape for at least the last 10,000 years and thus provide vital habitat for numerous wildlife and plant species that have adapted to the unique ecological conditions they afford (Fralish et al. 1991, Abrams 1992, McShea and Healy 2002, Rodewald and Abrams 2002). However, forest surveys indicate an overall lack of oak regeneration with a high potential for future replacement by later successional forest types. Termed the "mesophication" of the forests (Nowacki and Abrams 2008), this successional process is largely occurring at sites where oak less successfully competes with more shade-tolerant, mesic broad-leaved deciduous species, particularly in nutrient rich and moist sites and where disturbance, such as fire, is largely now absent (Crow 1988). In fact, in the Central Hardwood Forest Region of the U.S., the historical prevalence of oak is attributed to centuries of American Indian burning, and current oak dominance has been linked to the intensive logging, fire, and grazing activities of Euro-American settlers (Abrams 1992, Johnson et al. 2002). In both cases, anthropogenic disturbance has promoted the regional dominance of oak; oaks typically are more fire adapted than later-successional tree species and readily stump sprout under the appropriate conditions (Burns and Honkala 1990).

Over the last century, fire suppression is largely viewed as accelerating the successional process in oak-dominated forests (Nowacki and Abrams 2008). However, other complex, and often interrelated, ecological and social factors, such as increased herbivory by white-tailed deer, the spread of invasive species, and ill-planned harvests have also been linked to limiting the competitive advantage of oak (Abrams and Nowacki 1992, Meekins and McCarthy 1999, Kittredge et al. 2003, Rooney and Waller 2003). In particular, high-grading (a selective harvesting method where only high quality, economically valuable, mature trees are harvested) decreases the overall genetic quality of a forest stand over time and also does not provide openings in the canopy that are large enough to allow adequate light for oak recruitment; thereby, favoring more shade-tolerant species (Johnson et al. 2002, Kittredge et al. 2003). Clearcutting has been used to create suitable light conditions for oak, but this harvesting method can instead encourage succession to more shade-tolerant species if there is inadequate natural oak regeneration at the time of harvest (Abrams and Nowacki 1992). The layers of complex forces inhibiting successful oak regeneration suggest that the future of regional oak dominance and associated biodiversity are uncertain, if not imperiled (Fralish 2004). In response, natural resource agencies from various midwestern states have listed oak management as a priority (Iowa Department of Natural Resources 2005, Wisconsin Department of Natural Resources 2005). The steps required to achieve this priority, however, are poorly defined.

In an effort to begin a process that would define these steps, we sought to develop a holistic conceptual model and systems understanding of forest change and oak regeneration in the Driftless Area of the Midwest, with the intention of illuminating leverage points from which to improve oak forest resilience. Our set our objectives included: (1) describing the state of the oak system; (2) identifying key biophysical, ecological, and social components and processes that influence oak ecosystem dynamics; (3) revealing within- and cross-scale interactions, dependencies, feedbacks, thresholds, and critical system uncertainties; and (4) developing an understanding of the preferred attributes of future forest conditions in the region. These goals form a framework for our systems analysis and are adapted from Walker et al.'s (2002) resilience analysis and management approach. As Walker et al. (2002)

emphasize, this approach is designed to go beyond characterizing the system, but can identify points in the system where resilience to uncertain future changes can be increased.

RESEARCH APPROACH

Study area: The Driftless Area of the Midwest

The Driftless Area is roughly 5 million hectares in size, encompasses a part of the upper Mississippi River and portions of four states—southeastern Minnesota, southwestern Wisconsin, northeastern Iowa, and northwestern Illinois (Fig. 1). This region historically was a shifting mosaic of tallgrass prairie, bur oak savanna, and deciduous forest (Albert 1995). Similar to other areas in the eastern and midwestern U.S., the Driftless Area landscape has been substantially altered since Euro-American settlement, with the majority of native cover types converted to agricultural lands, especially on the floodplains and level uplands (Prior 1991, Albert 1995). Currently, forests make up nearly one-third of the landcover (USDA Forest Service 2005), over half of which is described as oak-hickory forest type (Fig. 2). Nearly all (approximately 90%) of forestland is in private ownership (USDA Forest Service 2005).

Forestlands in the Driftless Area are of ecological as well as social importance, as they are part of the working rural landscape of the region (Jacobs and Wray 1992). The forest cover in this region provides valuable habitat for a variety of wildlife and plant species (Pusateri et al. 1993, Wisconsin Department of Natural Resources 2005). In addition, the forested slopes are essential to soil conservation efforts, as the potential for soil erosion and agricultural runoff is high in this steeply dissected landscape (Trimble and Crosson 2000). As a social and economic asset, the steep forested slopes and trout streams pose an attractive vacation destination for people from three proximal major metropolitan areas: Minneapolis, Minnesota; Madison, Wisconsin; and Chicago, Illinois. While the amenity value of the Driftless Area contributes to the local economy, it is also a potential threat to forestland. Oak forests are more frequently converted to residential development in comparison to other cover types, especially near lakes and rivers (Kromroy et al. 2007). Radeloff et al. (2005) documented widespread urban sprawl between 1940 and 2000 throughout much of the Midwest, following the trend in other areas rich in amenity resources (Gustafson et al. 2005).

Qualitative Interviews

We used a qualitative research framework to provide insight into the key features of the oak forest system, recognized as a sub-system of the broader social-ecological landscape. Humans are a critical part of ecosystems and the future of ecosystem goods and services are reliant on understanding the features of human systems, including human behavior, which can contribute to either shifting the system into an undesirable state or improving its resilience. While quantitative methods are useful for answering many critical ecological and social questions, such methods have limited utility when trying to understand complex systems dynamics, especially when human behavior and perceptions are an essential component (Walker et al. 2002). Thus, qualitative social science research methods can offer further insight into complex issues, about which little is already known and for which innovative and flexible strategies are needed due to large uncertainties in the system (Strauss and Corbin 1990). Given the paucity of information on the economic and social factors influencing oak regeneration, qualitative methods were appropriate for addressing our objectives.

In landscapes composed of primarily privately-owned forestland, natural resource professionals can serve as key agents in the communication of regional forest conservation goals (West et al. 1988). Drawing upon adoption-diffusion terminology, natural resource professionals can be termed "change agents," or individuals who are directly involved in promoting or disseminating new knowledge or ideas (Rogers 2003). These professionals have a unique and multifaceted perspective, often having to negotiate the complex ecological and social context related to forest management on private lands. Therefore, natural resource professionals served as our main stakeholder group to provide insight into our research objectives.

Between October 2005 and May 2006, the lead author conducted semi-structured, in-depth, interviews with 32 natural resource professionals that worked in the Driftless Area. Interviewees were identified through a non-random selection process, described as snowball sampling, in which interviewees recommend other participants (Esterberg 2002), with the goals of interviewing individuals that had regular contact with private landowners and had a substantial amount of experience. We also sought to obtain diverse viewpoints; thus, the participant pool consisted of publicly-employed foresters (n=13), other publicly-employed natural resource specialists (e.g., forestry extension specialists; n=5), privately-employed forestry professionals (e.g., consulting foresters; n=8), and those employed by the timber industry (e.g., sawmill owners and loggers; n=6). The majority of interviewees had at least 20 years of experience in the region. Five interviewees had less than 10 years of experience; however, due to their position and/or level of engagement with private landowners, they were considered important actors within the system and thus included in the pool of research participants.

Each interview followed a similar overall format (Appendix 1); however, characteristic of semi-structured interviews, the follow-up questions (probes) were chosen according to individual participant's responses (Esterberg 2002). To broadly explore oak management as related to ecological and social contextual factors, we asked questions concerning forest resources and private lands management in general, and also inquired directly about the oak forest type (Appendix 1). The length of the interviews varied (ranging between 23 and 107 minutes) and averaged 49 minutes. Roughly half of the interviews (n=17) were conducted in person and the other interviews by telephone; interviews were digitally recorded and transcribed.

To analyze the interviews, sections of the transcribed text were coded and themes were developed using an "open coding" process (Esterberg 2002). The codes, themes, and thematic categories represent frequently encountered perspectives by the interviewees. However, ideas and perspectives that were mentioned rarely or sentiments that were contrary to the majority of opinions were also important to interpreting the findings (Strauss and Corbin 1990). The lead author used NVivo 7 qualitative analysis software (QSR International 2006) to assist with data management and analysis. We provide quotations from interviews to illustrate key findings (Appendix 2).

Systems Analysis

Systems thinking offers a basis for understanding and designing mechanisms for building resilience in complex systems (Walker et al. 2002, Allison and Hobbs 2006). In particular, systems theory provides the foundation for the holistic approach to understanding resilience, with attention to not only scale and system components, but relationships as well

(Checkland 1981, Allison and Hobbs 2006). For example, systems theory suggests that complex systems exhibit emergent properties that cannot be understood from examining individual components, but instead result from critical relationships (i.e., feedbacks and dependencies) among components (Checkland 1981). Thus, systems thinking embraces a holistic rather than reductionist perspective and has contributed to the development of numerous approaches to problem solving, including systems agriculture, management cybernetics, and management science (operations research) (Ison et al. 1997). We adopted a soft systems approach, drawing from the interview data to create causal loop diagrams that highlight key system variables and processes, relationships, and positive and negative feedbacks.

RESULTS

Our findings are arranged in three main sections: (1) natural resource professionals' perspectives on the state and resilience of the system, including a conceptual model of key system components, relationships, and feedbacks; (2) critical system thresholds, interactions, and uncertainties; and (3) interviewees' preferred attributes of future forestland.

Section 1: The state and resilience of the oak-dominated social-ecological system

We characterized the state of the oak forest socio-ecological system through analysis of data from interviews with natural resource professionals. We found that most professionals perceived the overall forest as degraded, with widespread decline in oak regeneration. Interviewees pointed to the impact of ecological, economic, and social factors on the forest resources and oak in particular; these factors influenced the system at different spatial and institutional scales (Appendix 2). In particular, landowners' decision to adopt oak management practices figured prominently in the state of the system (Knoot et al., in review) and was central to our conceptual model (Figs. 3 – 6). Three main thematic categories (main features of the system) emerged from the interviews, which were directly and indirectly associated with landowner decision making, including: (1) the direct and indirect influence of ecological factors on oak regeneration (Fig. 4); (2) the inhibiting effect of macro-level socioeconomic processes on landowner oak management decisions (Fig. 5); and (3) personal relationships which promote oak-appropriate decision making (Fig. 6). In combination, these system components and processes comprise the holistic conceptual model of the Driftless Area oak forest social-ecological system (Fig. 7).

Category 1: The direct and indirect influence of ecological factors on oak regeneration

Interviewees identified several ecological factors that influenced landowners' decision to adopt oak management practices, most often indirectly through their influence on the economic cost of oak regeneration (Fig. 4). Following the central positive feedback loop (L1+, Fig. 4), landowner adoption of oak management practices (e.g., prescribed fire, extensive overstory tree removal, and manual removal of understory vegetation) improves the biophysical conditions for oak regeneration, thereby increasing oak sapling and seedling growth, and decreasing the economic cost of regenerating oak. Interviewees noted, for example, that when a stand contains adequate advanced regeneration of oak, fewer practices (e.g., direct seeding and planting of oak) are needed for re-establishing oak at a site. A lower economic cost for oak regeneration increases the likelihood that landowners will choose to adopt oak regeneration practices in the future.

The two negative feedback loops link the spread of invasive oak pests and diseases to landowner oak management decisions (L2- and L3-; Fig. 4), and serve to dissuade landowners from adopting oak management practices. The majority of interviewees remarked on an increase in the impact of oak pests and diseases on mature oak stands throughout their region. They most often cited gypsy moth (*Lymantria dispar*), two-lined chestnut borer (*Agrilus bilineatus*), and oak wilt, caused by a fungal pathogen (*Ceratocystis fagacearum*), as main threats to the oak resource. Such pests and diseases negatively impact mature oak trees and, thus, stand-level dominance. In turn, they can limit the future spread of pests and diseases of oak (L3-). Several professionals noted that landowners are less likely to choose to adopt oak regeneration practices if future oak-dominated stands perceived to be at risk of infestation (L2-).

The majority of natural resource professionals have found white-tailed deer (*Odocoileus virginianus*) herbivory, invasive plants growth, and the advanced regeneration of sugar maple in the understory as negatively impacting oak seedling and sapling growth, thereby increasing the economic cost of oak regeneration and decreasing the likelihood that landowners will adopt oak management practices (Fig. 4). For example, to prevent deer herbivory, the professionals recommended the use of tree shelters, an additional cost to landowners. Invasive plants were also commonly viewed by the interviewees as a top threat to oak in the region, directly inhibiting oak seedling and sapling growth, and requiring increased effort and expense to remove. The professionals cited European buckthorn (*Rhamnus cathartica*) and garlic mustard (*Alliaria petiolata*) most often, among over a dozen other species.

The increased advance regeneration of sugar maple in many forest stands was thought to be influenced by past and current land management decisions, specifically high-grading and site productivity (Fig. 4). Many interviewees expressed their perception that high-grading was a product of short-term economic decision making by private landowners, carried-out, and sometimes encouraged, by some individuals in the logging industry. The professionals remarked that high-grading often retained the overstory canopy and thus favored later-successional, more shade-tolerant species, such as sugar maple.

Notably, the natural resource professionals did not discuss climate change as an issue affecting oak regeneration. We decided to include this process in the model due to the widespread impact that climate change could have on forest composition and specifically oak in the region. For example, some ecological models suggest that climate change will result in an increase in suitable conditions for oak, specifically white oak (*Quercus alba*) (Prasad et al. 2007).

Category 2: The inhibiting effect of macro-level socioeconomic processes on landowner oak management decisions

The second main group of system components and processes includes predominately macro-level economic and social variables that were noted by professionals to influence the oak system and, specifically, landowner adoption of oak management practices (Fig. 5). For example, several of the interviewees remarked on the strong market price for sugar maple, which in the recent past was equal to or exceeded the stumpage price for red oak (*Quercus rubra*). These market forces were thought to decrease the likelihood of landowners choosing to adopt oak regeneration practices, especially given that managing for oak was considered more expensive than managing for sugar maple.

We also found that the professionals were deeply concerned about the widespread trend in forestland parcelization; they connected parcelization to the fragmentation of once contiguous forests by residential housing development (Chapter 2). The main negative feedback (L4-, Fig. 5) in this part of the system centers on forest parcelization. Many interviewees believed that societal demand for the amenities provided by rural forestland had contributed to its increasing the economic value and, thus, increased the likelihood that a landowner would choose to sell a portion of their land (i.e., parcelization). The interviewees also remarked that oak management practices often result in a decrease in the short-term aesthetic appeal of the property. Aesthetics were thought by interviewees to be a top priority of landowners (Chapter 2). Since oak management often causes a short-term decline in property aesthetics, several professionals posited that once landowners view the outcomes of oak management prescriptions (i.e. extensive overstory removal), they may be more likely to sell and parcelize their property. Landowners that intend to own their property for only a short duration are less likely to adopt oak management, which is a long-term endeavor. Together these factors form a negative feedback loop in the system (L4-, Fig. 5), and constrain landowner adoption of oak management practices.

We also found that interviewees saw parcelization as directly and indirectly increasing landscape-level economic and operational constraints to oak management, thus decreasing the likelihood that landowners adopt oak management practices (L5- and L6-; Fig. 5). For example, the professionals noted the challenges associated with carrying-out timber harvests (a tool for encouraging oak regeneration) on small parcels and near houses (Chapter 2). The professionals have also found that with an increase in exurban housing development, more landowners have direct and frequent contact with their forested property. They linked this phenomenon to an increase in the proportion of landowners placing importance on the non-timber attributes (e.g., aesthetics, hunting, recreation, privacy) of their lands; values that most interviewees have found to conflict with the perceived outcomes of oak management practices and, therefore, a deterrent to landowners' adoption of these practices (L7-, Fig. 5). In addition, several natural resource professionals noted an increase in the number of landowners that post their property against public hunting, deemed a result of their own interest in hunting their property and also the importance they place on privacy.

As an important relationship between social and ecological features of the system, several of the interviewees linked the decline in public hunting of privately-owned lands to an increase in deer herbivory (L10-, Fig. 7), connecting human behavior to a main ecological factor inhibiting landowner adoption of oak management (Fig. 4).

Category 3: Personal relationships promote oak-appropriate decision making

Interviewees placed high importance on the relationship between the professionals and landowners (Fig. 6). The professionals described their interactions as increasing landowners' knowledge of oak ecology and potential management prescriptions, as well as providing landowners access to forest management incentive programs (Chapter 2). Both features directly and indirectly increase the likelihood that a landowner will adopt oak management practices, creating positive feedbacks in the system (L8+ and L9+; Fig. 6). Thus, we found that while parcelization can reduce the likelihood for oak management by landowners (Fig. 5), there are potential beneficial outcomes. For example, the professionals described parcelization as often resulting in a greater number of landowners seeking forestry assistance.

Section 2: Critical system thresholds, interactions, and uncertainties

Perceived system thresholds

We identified two main ecological thresholds that were discussed by interviewees, namely the level of deer herbivory in the region and the amount of resource competition (i.e., population levels of woody and herbaceous understory plants) facing oak regeneration. The professionals suggested that, once above a certain level of herbivory or competition, the expense (i.e., economic and personal effort) to counteract these processes exceeded what most owners were able and/or willing to spend. Also, several professionals noted that at some threshold, the current techniques for removal of competing plants became ineffective.

Many interviewees also noted the threshold related to parcel size and the feasibility of management options. In their experience, once parcelization had progressed to the point where parcels fell below a certain size, the economies of scale became critical to determining whether a timber company would be able and/or willing to harvest on that parcel.

Cross-scale interactions

Through our analysis of interviews and conceptual modeling approach, we identified several cross-scale (temporal, spatial, and institutional) interactions. First, we found that the length of parcel ownership—the typical time that landowners experience their properties—was perceived to influence their land management priorities, such that shorter land tenure resulted in landowners placing greater importance on the immediate outcomes of forest management practices. As noted by the interviewees, this phenomenon, often augmented by forest parcelization, is in direct conflict with the time frame required to regenerate an oak forest following harvesting; it takes at least 10 years for the overstory canopy to close and several decades to grow a mature oak forest. Thus, regenerating an oak forest requires a time period that usually exceeds the typical land tenure (suggested to be less than 15 years).

In addition, we found that parcel-level land management decisions can have a regional influence on oak regeneration. For example, interviewees expressed the notion that a landowner posting "no hunting" on their property increased deer fitness at their site, potentially contributing to regionally high population levels and seedling herbivory. Thus, site-level expenses for oak management are influenced by regional level ecological (deer population growth) and social processes (human behavior). Invasive plant growth was also thought to influence site-level expenses; however, multi-parcel, regional, national, and global issues all contribute to the spread of invasive species. Finally, the natural resource professionals identified both macro-level factors that influenced forestland parcelization (e.g., regional property values) and site-level factors (e.g., property aesthetics) that together served to demote individual landowner decision making to perpetuate oak.

System uncertainties

The majority of natural resource professionals believed that they were well-equipped with a variety of silvicultural tools for encouraging oak regeneration, but many interviewees felt uncertain about how to manage and prepare for the influence of future invasive pests, disease, and plants on forest resources. In addition, most of the interviewees perceived the continued parcelization of forestland and exurban sprawl as looming threats to the forest resources in general, and oak in particular, and were unsure of how they could personally counter these trends.

Section 3: Preferred attributes of future forestland

We asked the professionals about their preferred attributes of the future forest resources and of oak-dominated forests in particular. The main responses we encountered were tied directly to some of the main uncertainties that they identified in the system. We identified three main attributes: (1) diverse and resilient forests, (2) secure forest extent, and (3) maintenance of an oak component at stand and/or landscape scales. As invasive pests, diseases, and plants were of great concern to the professionals; most interviewees told us that they would like to see forests that contain a diversity of species and age classes. They linked this diversity to the ability of the forest to withstand future pests and disease outbreaks, i.e., enhancing system resilience to these potential disturbances and ensuring future access to valued tree species. Interviewees also preferred diverse age-classes, also in an effort to provide stable resources for future generations.

The security of the resource was also sought by many interviewees, as reflected in their preference for maintaining or expanding the amount of forest cover on the landscape. This preference was linked to their concern over further exurban housing development and forest parcelization. Both factors were thought to reduce future access to the timber resource by either eliminating the resource through clearing of the land for housing, or increasing the constraints to timber harvesting by reducing parcel size. Thus, we regularly heard that the region needs to "keep forest as forest."

Finally, given the important benefits that oak-dominated forests provide to society, we were surprised to encounter the frequent preference for maintaining an "oak component," at stand and/or landscape scales. Many interviewees suggested that a reduction in the dominance of oak in the future was acceptable, as long as some oak was perpetuated; interviewees' definitions for what proportion of oak was considered acceptable varied considerably. We found this preference to be tightly linked to the overall system dynamics (Fig. 6). The majority of ecological, economic, and social factors constrain landowner adoption of oak management practices, either directly or indirectly. Thus, the professionals appeared to perceive oak management as a costly and frustrating endeavor, both personally and from the standpoint of private landowners. Many viewed an oak component, as opposed to oak dominance, as more realistic and even preferable given current pressures, especially those associated with oak pests and diseases. Thus, to safeguard the future resources, more diverse stands appeared to be preferable to the professionals.

In addition, many professionals believed that the trajectory of forest change (i.e., successional shift to later-successional species) was well established. In other words, current thresholds have already been crossed, making management for oak dominance too costly to be attempted. We also heard from a professional about his/her concern that promoting oak could also lead to the loss of future resources. If landowners are dissatisfied with oak management outcomes, they may sell and parcelize their property, potentially contributing to further exurban housing development.

DISCUSSION

Walker et al. (2004) describe three main attributes that shape the future of social-ecological systems: resilience, adaptability, and transformability. Through our analysis of the interviews, we found that the collective perspectives of the natural resource professionals directly or indirectly applied to these three aspects of the social-ecological systems. We, thus used these attributes as a lens from which to interpret our study findings.

Resilience of oak ecosystems: changes to the stability domain and landscape

The landscape in the Driftless Area prior to and just following Euro-American settlement provided a set of conditions that favored disturbance-dependent oak forests, with later-successional forest types comprising a smaller proportion of the landscape than today. This landscape can be thought of as a “stability landscape,” with various forest types represented as stability domains (Gunderson 2000). Resilience refers to the attributes that allow the system to remain in that particular domain, retaining key system components, processes, and functions despite disturbance. There are four main attributes that describe system resilience: (1) latitude, or the maximum amount a system can change before reaching a threshold; (2) resistance of a system to change; (3) precariousness, or how close the system is to a threshold; and (4) panarchy, which refers to the cross-scale system processes—the system at one focal scale is influenced by systems components and processes at broader and finer scales (Walker et al. 2004). The ball and cup heuristic (Gunderson 2000) provides a visual of the four features of resilience; the ball represents the state of the system and the cup is the stability domain, with one or more cups forming the stability landscape (Fig. 8).

The natural resource professionals clearly articulated a change in the shape of the stability domain and stability landscape over time in our study region. Wider domains (greater latitude), with steeper sides (greater resistance to change), indicate increased system resilience. The stability domain for oak in the region appears to have decreased in latitude and resistance, with increasing precariousness, due to both ecological and social system features (Fig. 8). For example, an important threshold in the system was the proliferation of understory plant competition. With a change in the disturbance regime in the region, namely fire suppression and high-grading, more shade-tolerant species have thrived in the understory, decreasing system resistance to change. The invasion of non-native plants in the understory has also contributed to reducing resistance, as well as moving the system closer towards the threshold (increasing precariousness). Further decreasing system resilience, deer herbivory appears to have reduced the latitude (width) of the domain, inhibiting oak regeneration and moving the threshold closer to the current state of the system (i.e., with less oak regeneration due to herbivory, there is a lower threshold for understory plant competition before the system shifts into an alternate state) (Fig. 8).

Adoption of oak management practices, such as prescribed fire, could help to retain the shape of the oak stability domain; however, forest parcelization and exurban development, in addition to the ecological factors described above, have contributed to reducing the likelihood that landowners adopt oak management practices. The main alternatives to oak management were typically noted to be high-grading and no management, which alter the shape of the stability domain for oak and potentially the overall stability landscape. For example, widespread high-grading and lack of management by landowners appears to shrink the stability domain for oak while increasing the latitude and resistance of the domains of other forest types (e.g., sugar maple-basswood).

In the northeastern U.S., where ownership patterns closely parallel those in our study region, Kittredge et al. (2003) documented the pervasive and non-random pattern of high-grading across the landscape, which they expect to result in forest and landscape homogeneity. The results from our interviews suggest that with the decline in oak-dominated forests, homogenization of the forest landscape is also possible in our region. The potential for creating new stability domains with novel species compositions (Seastedt et al.

2008) also exists within this landscape, such as forests with a larger component of invasive shrub species. This type of shift in the stability landscape was deemed highly undesirable by the natural resource professionals, but they felt they did not have the capacity to cope with it. These natural resource professionals typically apply their expertise to forest stand and properties, whereas management of invasive plants requires a broader-scale approach; i.e., attention to system panarchy.

Panarchy is the fourth attribute that helps to describe system resilience and relates to the importance of scale; the state of the system at a particular focal scale (i.e., oak-dominated forests) is influenced by broader (i.e., forest landscape) and finer (i.e., oak tree) scales (Gunderson and Holling 2002, Walker et al. 2004). We identified critical cross-scale interactions that offer the potential to influence oak system resilience. For example, climate change, market forces (i.e., stumpage prices for oak and maple), invasive species spread, societal demand for rural forestland, and forestland parcelization and exurban sprawl, operate at broader scales (from regional and global) but have cascading effects on landowner decision making at the forest stand level. Thus, policy mechanisms and management approaches must address these multi-scale system drivers. One such approach is cross-boundary cooperation, where neighboring landowners coordinate their management to achieve landscape-level outcomes, such as timber supply or invasive species removal (Kittredge 2005). Where forest parcelization and exurban sprawl contribute to less-marketable timber volumes, cross-boundary cooperation offers the potential to broaden the scale of management, with potentially beneficial ecological, economic, and social outcomes (Kittredge 2005). For example, since invasive plants and deer are not attentive to political borders, cross-boundary cooperation is essential to tackling these critical constraints on oak regeneration.

Adaptability

The second feature that shapes the future of social-ecological systems is the ability of system actors to adapt to change and maintain system resilience. In the context of managing for oak in our region, removing the constraints on this disturbance-dependent system requires the collective effort of actors operating at multiple institutional scales (e.g., individual landowners, natural resource professionals, conservation organizations, and regional and national-level policy makers). As mentioned previously, various natural resource organizations have listed oak management as a priority. However, our findings suggest that the natural resource professionals were most interested in bolstering system resilience at the scale above oak-dominated forests (i.e., forest landscape), seeking to ensure future access to valued timber species. To achieve this goal, many professionals accepted a loss of resilience in oak forests (i.e., the shrinking of the oak system domain), especially if the system shifts to sugar maple-basswood; a system deemed economically beneficial and more palatable to landowners.

Yet, the resilience of the forest landscape not only depends on economic diversity, but also on biodiversity and ecological heterogeneity. A loss of oak-dominance could have cascading ecological effects on the numerous species that depend on the conditions afforded by oak forests (Fralish 2004). While humans and markets may adapt to the shift in availability of the timber resource, the future of oak-associated flora and fauna is questionable. In addition, the interviewees stated that less-intensive forest practices were acceptable and often preferred. However, taken in the aggregate, the decisions of the numerous landowners in the region to selectively harvest their forests may result in overall landscape homogeneity (Kittredge et al. 2003), with a loss of resilience at this broader scale.

Although not directly discussed by interviewees, climate change may be a critical system uncertainty. While the interviewees regarded the shift in the stability landscape towards sugar maple-basswood forests potentially economically advantageous, this shift may be unstable in the long-term. For example, climate change models point to a decline in suitable conditions for sugar maple, with an expansion in the habitat appropriate for white oak (Prasad et al. 2007). A decline in oak-dominated forests in the short-term, however, would decrease the potential for natural regeneration of future oak forests in the future, and the expense of restoring oak may then be cost prohibitive despite suitable ecological conditions (Nowacki and Abrams 2008). Therefore, if the domain for sugar maple shrinks due to climate change, there is potential for an increase in a domain that includes novel species compositions, including undesirable species such as European buckthorn.

Adaptability refers to the purposeful shaping of the stability landscape to retain resilience (Walker et al. 2004). If the resilience of oak forests is deemed socially desirable, there must be dialogue among key regional stakeholders to design proactive approaches that address the multi-level constraints to oak management and capitalize on the opportunities for influencing landowner behavior (i.e., relationships between the professionals and private landowners, economic incentives). Given the current trajectory of change in the system, there is also a need to envision alternative preferred system states and create practical solutions that can prevent the loss of valued ecosystem goods and services due to shifts towards undesirable systems.

Transformability

Such envisioning of alternative futures is crucial to system transformability (Peterson et al. 2003a). Where adaptability refers to the capacity of actors to retain the structure of the stability landscape, transformability is instead the ability of actors to reshape the stability landscape—still providing valued ecosystem goods and services—when current ecological, economic, and social conditions appear unworkable (Walker et al. 2004). The natural resource professionals provided us with preferred attributes of future forestland conditions, including ready access to valued timber species, a halt to further forest parcelization and exurban housing development, and the maintenance of the forest extent; however, steps towards achieving these goals appeared to be ill-defined. As the future of non-native species invasions, forest parcelization, and ecological conditions associated with climate change remain uncertain, the envisioning of alternative scenarios could initiate a discussion on the next steps and create the partnerships needed for action (Walker et al. 2004).

Overall, our study illuminated key system components and processes, and highlighted potential system uncertainties that could be used to create alternative visions of the future (Peterson et al. 2003b)—addressing aspects of the first two steps in the resilience analysis and management approach (Walker et al. 2002). The experiential knowledge of the natural resource professionals provided a holistic view of the system; experimental knowledge (e.g., quantitative evaluation of thresholds related to understory competition and the economic expense of oak regeneration) is now needed to identify cause and effect and provide access to those seeking action (Fazey 2005).

ACKNOWLEDGEMENTS

We wish to thank the research participants for sharing their experiences and insights. Project guidance and helpful review comments were provided by R. Atwell, N. Grudens-Schuck, J. Miller, and M. Rickenbach. C. Eberle, B. Jan, A. MacDonald, K. Smith, and M. Boyd participated in transcribing interviews. We received funding from the USDA Forest Service – Northern Research Station and Iowa State University. T. Knoot was a research fellow with the U.S. EPA – STAR Graduate Fellowship Program. EPA has not officially endorsed this publication and the views expressed herein may not reflect the views of EPA.

LITERATURE CITED

Abrams, M. D. 1992. Fire and the development of oak forests. *Bioscience* **42**:346-353.

Abrams, M. D. 2005. Prescribing fire in the Eastern oak forests: is time running out? *Northern Journal of Applied Forestry* **22**:190-196.

Albert, D. A. 1995. *Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification.* Gen. Tech. Rep. NC-178, USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota, USA.

Abrams, M. D., and G. J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. Bulletin of the Torrey Botanical Club **119**:19-28.

Allison, H. E., and R. J. Hobbs. 2006. *Science and policy in natural resource management: understanding system complexity.* Cambridge University Press, Cambridge, UK.

Bliss, J. C. 2000. Public perceptions of clearcutting. *Journal of Forestry* **98**:4-9.

Burns, R. M., and B. H. Honkala, technical coordinators. 1990. *Silvics of North America: hardwoods.* Agriculture Handbook 654, vol.2. U.S. Department of Agriculture, Forest Service, Washington, DC.

Butler, B. J., and E. C. Leatherberry. 2004. America's family forest owners. *Journal of Forestry* **102**:4-9.

Chapin, F. S., III, T. S. Rupp, A. M. Starfield, L. DeWilde, E. S. Zavaleta, N. Fresco, J. Henkelman, and A. D. McGuire. 2003. Planning for resilience: modeling change in human-fire interactions in the Alaskan boreal forest. *Frontiers in Ecology and the Environment* **1**:255-261.

Checkland, P. B. 1981. *Systems thinking, systems practice.* John Wiley & Sons, Chichester UK.

Cissel, J. H., F. J. Swanson, and P. J. Weisberg. 1999. Landscape management using historical fire regimes: Blue River, Oregon. *Ecological Applications* **9**:1217-1231.

Crow, T. R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*): a review. *Forest Science* **34**:19-40.

Cumming, G. S., D. H. M. Cumming, and C. L. Redman. 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. *Ecology and Society* **11**(1): 14. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art14/.

Delcourt, H. R., and P. A. Delcourt. 1997. Pre-Columbian Native American use of fire on Southern Appalachian landscapes. *Conservation Biology* **11**:1010-1014.

Drever, C. R., G. Peterson, C. Messier, Y. Bergeron, and M. Flannigan. 2006. Can forest management based on natural disturbance maintain ecological resilience? *Canadian Journal of Forest Research* **36**:2285-2299.

Esterberg, K. G. 2002. *Qualitative Methods in Social Research.* McGraw-Hill, Boston, Massachusetts, USA.

Fazey, I., J. A. Fazey, and D. M. A. Fazey. 2005. Learning more effectively from experience. *Ecology and Society* **10**(2): 4. [online] URL: http://www.ecologyandsociety.org/vol10/iss2/art4/.

Fralish, J. S. 2004. The keystone role of oak and hickory in the central hardwood forest. Pages 78-87 *in* M. A. Spetich, editor.*Upland oak ecology symposium: history, current conditions, and sustainability.* Gen. Tech. Rep. SRS-73, USDA Forest Service, Southern Research Station, Asheville, North Carolina.

Fralish, J. S., F. B. Crooks, J. L. Chambers, and F. M. Harty. 1991. Comparison of presettlement, second-growth and old-growth forest on six site types in the Illinois Shawnee Hills. *American Midland Naturalist* **125**:294-309.

Franklin, J. F., T. A. Spies, R. VanPelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbance and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* **155**:399-423.

Gunderson, L. H. 2000. Ecological resilience—in theory and application. *Annual Review of Ecology and Systematics* **31**:425-439.

Gunderson, L. H., and C. S. Holling, editors. 2002. *Panarchy: Understanding transformations in human and natural systems.* Island Press, Washington, D.C., USA.

Gustafson, E. J., R. B. Hammer, V. C. Radeloff, and R. S. Potts. 2005. The relationship between environmental amenities and changing human settlement patterns between 1980 and 2000 in the Midwestern USA. *Landscape Ecology* **20**:773-789.

Hessburg, P. F., J. K. Agee, and J. F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras. *Forest Ecology and Management* 211:117-139.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* **4**:1-23.

Holling, C. S., and G. K. Meffe. 1996. Command and control and the pathology of natural resource management. *Conservation Biology* **10**:328-337.

Iowa Department of Natural Resources. 2005. *Forest stewardship spatial analysis project.* [Online] URL: http://www.fs.fed.us/na/sap/products/ia.shtml.

Ison, R. L., P. T. Maiteny, and S. Carr. 1997. Systems methodologies for sustainable natural resources research and development. *Agricultural Systems* **55**:257-272.

Jacobs, R.D., and R.D. Wray. 1992. *Managing oak in the Driftless Area*. Publication number BU-05900. Minnesota Extension Service, University of Minnesota, St. Paul, Minnesota.

Johnson, P. S., S. R. Shifley, and R. Rogers. 2002. *The ecology and silviculture of oaks.* CABI Publishing, New York, New York, USA.

Kittredge, D. B. 2005. The cooperation of private forest owners on scales larger than one individual property: international examples and potential application in the United States. *Forest Policy and Economics* **7**:671-688.

Kittredge, D. B., Jr., A. O. Finley, and D. R. Foster. 2003. Timber harvesting as ongoing disturbance in a landscape of diverse ownership. *Forest Ecology and Management* 180:425-442.

Knoot, T. G., L. A. Schulte, and M. Rickenbach. In review. Oak conservation and restoration on private forestlands: negotiating a social-ecological landscape. *Restoration Ecology.*

Kromroy, K., K. Ward, P. Castillo, and J. Juzwik. 2007. Relationships between urbanization and the oak resource of the Minneapolis/St. Paul Metropolitan area from 1991 to 1998. *Landscape and Urban Planning* **80**:375-385.

McShea, W. J., and W. M. Healy. 2002. Oaks and acorns as a foundation for ecosystem management. Pages 1-9 *in* W. J. McShea and W. M. Healy, editors. *Oak forest ecosystems: ecology and management for wildlife*. The Johns Hopkins University Press, Baltimore, Maryland, USA.

Meekins, J. F., and B. C. McCarthy. 1999. Competitive ability of *Alliaria petiolata* (Garlic mustard, Brassicaceae), an invasive, nonindigenous forest herb. *International Journal of Plant Sciences.* **160**:743-752.

Nowacki, G. J., and M. D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. *Bioscience* **58**:123-138.

Palik, B. J., R. J. Mitchell, and J. K. Hiers. 2002. Modeling silviculture after natural disturbance to sustain biodiversity in the longleaf pine (*Pinus palustris*) ecosystem: balancing complexity and implementation. *Forest Ecology and Management* **155**:347-356.

Palik, B. J., and K. S. Pregitzer. 1992. A comparison of presettlement and present-day forests on two bigtooth aspen-dominated landscapes in Northern Lower Michigan. *American Midland Naturalist* **127**:327-338.

Peterson, G.D., G. S. Cumming, and S. R. Carpenter. 2003a. Scenario planning: A tool for conservation in an uncertain world. *Conservation Biology* **17**:358-366.

Peterson, G.D., T.D. Beard, Jr., B.E. Beisner, E.M. Bennett, S.R. Carpenter, G.S. Cumming, C.S. Dent, and T.D. Havlicek. 2003b. Assessing future ecosystem services: a case study of the Northern Highlands Lake District, Wisconsin. *Conservation Ecology* **7**(3): 1. [online] URL: http://www.consecol.org/vol7/iss3/art1.

Platt, W. J., G. W. Evans, and S. L. Rathbun. 1988. The population dynamics of a long-lived conifer (*Pinus palustris*). *The American Naturalist* **131:**491-525.

Prasad, A. M., L. R. Iverson., S. Matthews., M. Peters. 2007. *A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States* [database]. Northern Research Station, USDA Forest Service, Delaware, OH. [Online] URL: http://www.nrs.fs.fed.us/atlas/tree.

Prior, J. C. 1991. *Landforms of Iowa.* University of Iowa Press, Iowa City, Iowa, USA.

Pusateri, W. P., D. M. Roosa, and D. R. Farrar. 1993. Habitat and distribution of plants special to Iowa's Driftless Area. *Journal of the Iowa Academy of Sciences* **100**:29-53.

QSR International. 2006. NVivo 7. QSR International, Victoria, Australia.

Radeloff, V. C., D. J. Mladenoff, and M. S. Boyce. 2000. A historical perspective and future outlook on landscape scale restoration in the northwest Wisconsin Pine Barrens. *Restoration Ecology* **8**:119-126.

Radeloff, V. C., R. B. Hammer, and S. I. Stewart. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and its relation to forest fragmentation. *Conservation Biology* **19**:793-805.

Rodewald A. D., and M. D. Abrams. 2002. Floristics and avian community structure: implications for regional changes in eastern forest composition. *Forest Science* **48**:267-272.

Rogers, E. M. 2003. *Diffusion of innovations.* Fifth edition. Free Press, New York, New York, USA.

Rooney, T. P., and D. M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management* **181**:165-176.

Schulte, L. A., D. J. Mladenoff, T. R. Crow, L. C. Merrick, and D. T. Cleland. 2007. Homogenization of northern U.S. Great Lakes forests due to land use. *Landscape Ecology* **22**:1089-1103.

Seastedt, T. R., R. J. Hobbs, and K. N. Suding. 2008. Management of novel ecosystems: are novel approaches required?. *Frontiers in Ecology and the Environment* **6**: doi:10.1890/070046.

Strauss, A., and J. Corbin. 1990. *Basics of qualitative research: grounded theory procedures and techniques.* Sage Publications, Newbury Park, California, USA.

Suding, K. N., K. L. Gross, and G. R. Houseman. 2004. Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution* **19**:46-53.

Trimble, S. W. and P. Crosson. 2000. U.S. soil erosion rates—myth and reality. *Science* **289**:248-250.

US Forest Service. 2006. *Forest inventory and analysis DataMart*, version 3.0. [On-line] URL: http://fiatools.fs.fed.us/fiadb-downloads/fiadb3.html.

US Forest Service. 2007. *Forest inventory and analysis database: Database description and users guide*, version 3.0. National Forest Inventory and Analysis Program, USDA For. Serv. 230 p.

Walker, B., S. R. Carpenter, J. Anderies, N. Abel, G. S. Cumming, M. Janssen, L. Lebel, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems: A working hypothesis for a participatory approach. *Conservation Ecology* 6(1):14. [online] URL: http://www.consecol.org/vol6/iss1/art14.

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience, adaptability, and transformability in social-ecological systems. *Ecology and Society* **9**(2): 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art5.

West P. C., J. M. Fly, D. J. Blahna, and E. M. Carpenter. 1988. The communication and diffusion of NIPF management strategies. *Northern Journal of Applied Forestry* **5**:265-270.

Wisconsin Department of Natural Resources. 2005. *Wisconsin's strategy for wildlife species of greatest conservation need.* Pub-ER-641, Madison, Wisconsin, USA.

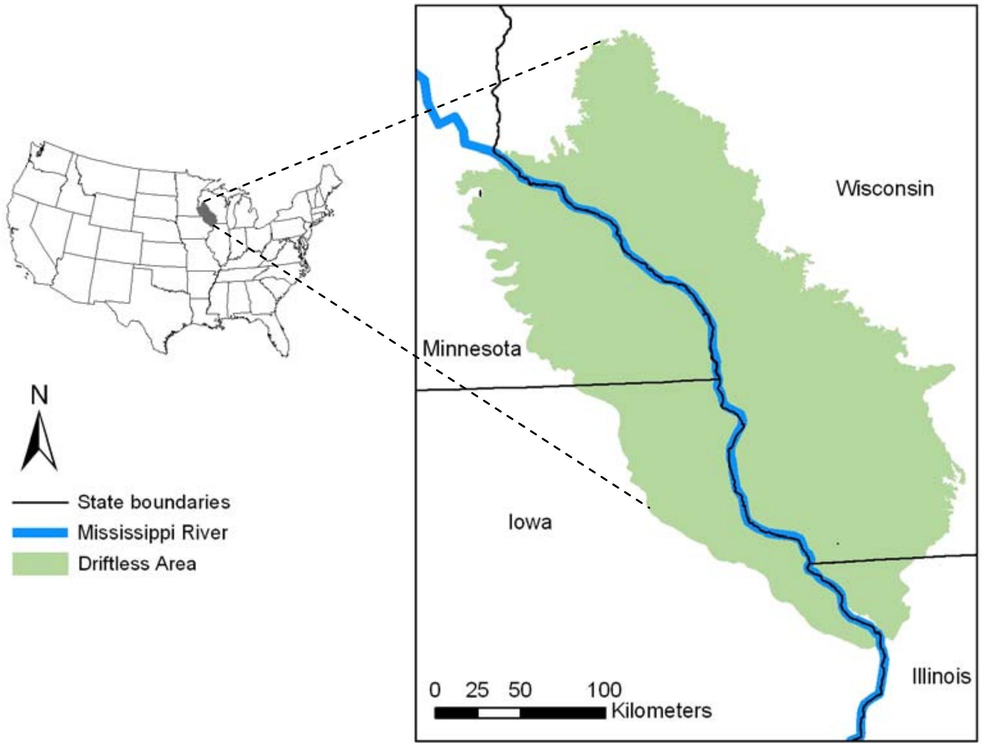

Fig. 1. Driftless Area of the midwestern U.S., encompassing portions of four states.

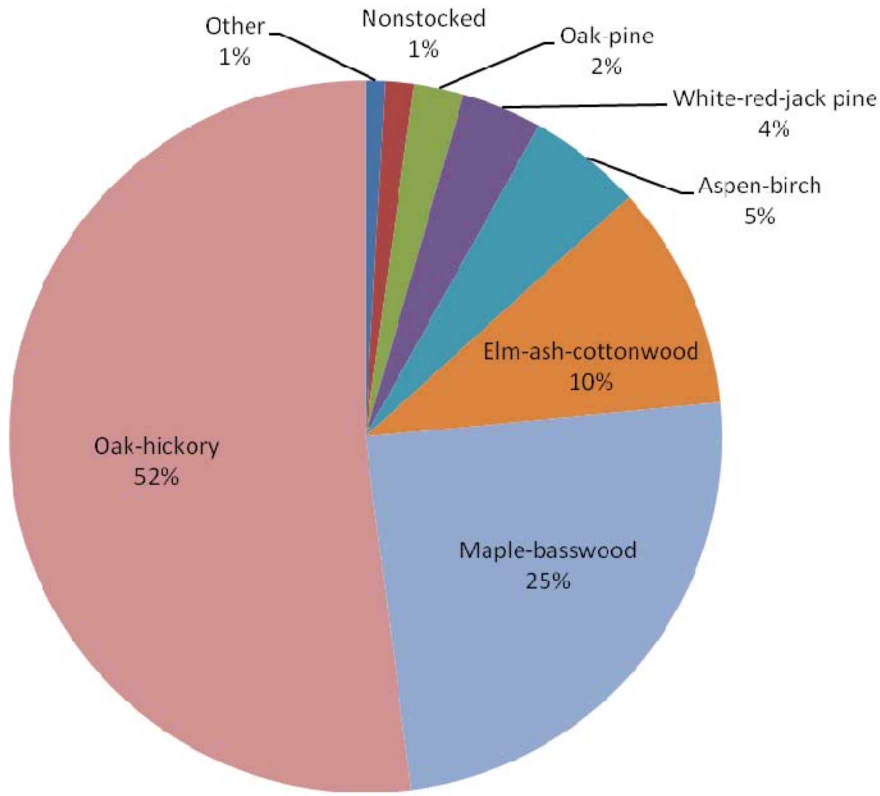

Fig. 2. Six most common forest types in the Driftless Area of the Midwest (US Forest Service 2006). Maple-basswood represents the forest type group maple-beech-birch, as designated by the US Forest Service (2007). Maple-basswood is most descriptive of the dominant tree species within this group in our study region.

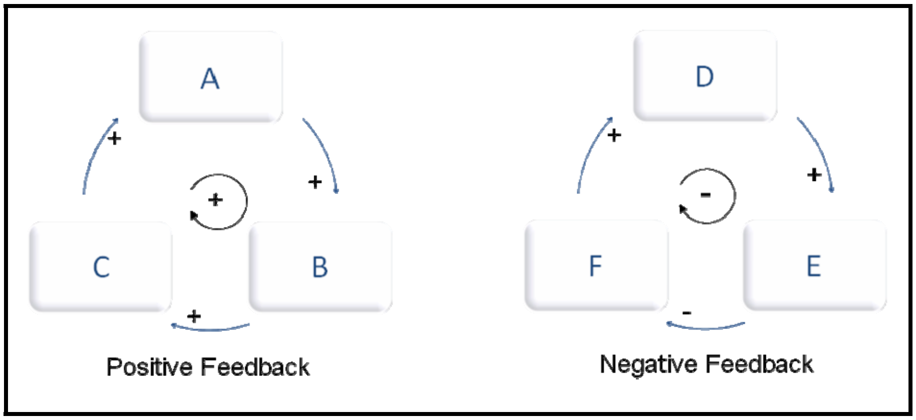

Fig. 3. Examples of causal loop diagrams, representing positive and negative feedback loops. A positive sign linking two variables (e.g., between A and B) indicates that A adds to B, or a change in A produces a change in B in the *same direction*. A negative sign linking two variables indicates an inverse relationship. For example, E subtracts from F, or a change in variable E produces a change in variable F in the *opposite direction*. To determine whether a negative or positive feedback occurs, count the number of negative causal links within the loop; an even number of negative links indicates a positive feedback and an odd number of negative links indicates a negative feedback.

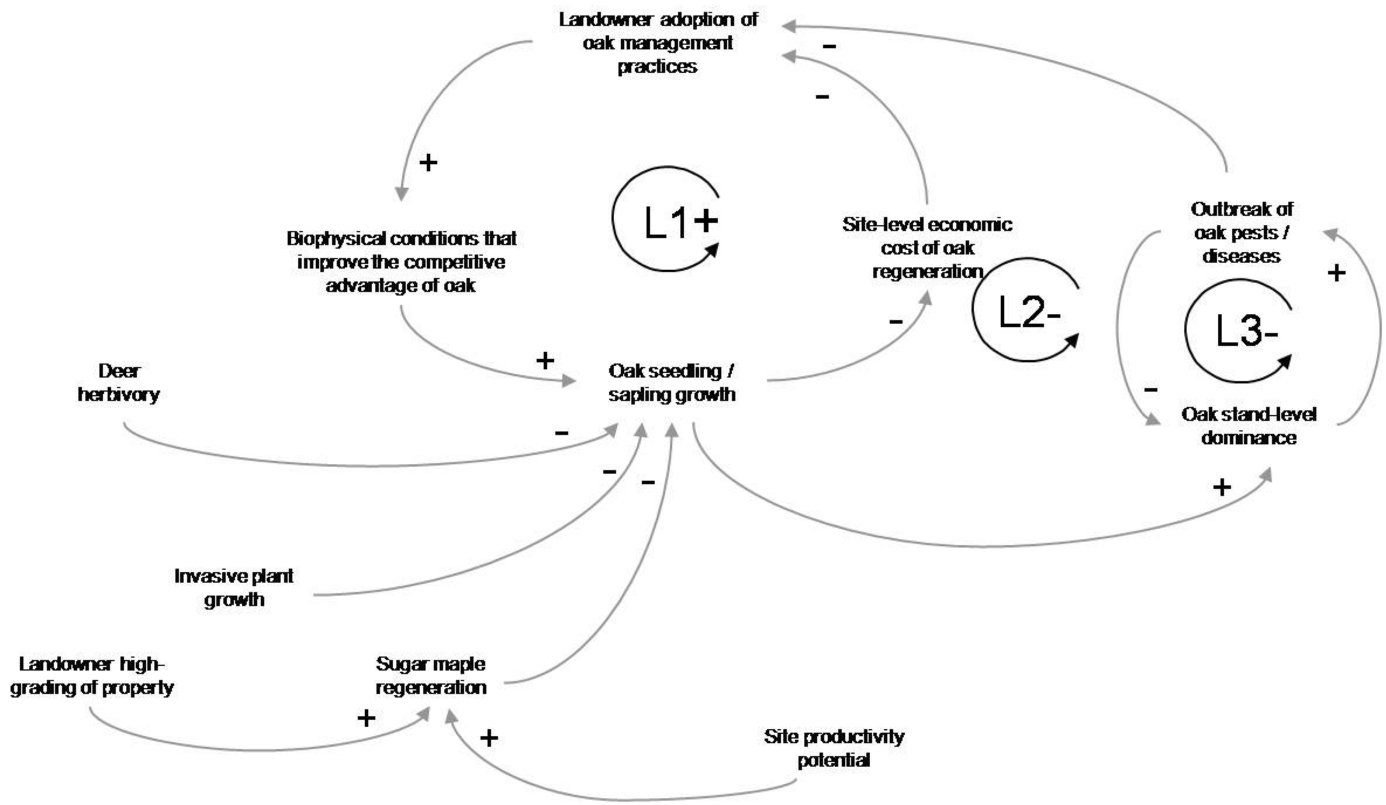

Fig. 4. The direct and indirect influence of ecological factors on oak regeneration. Landowner adoption of oak management practices improves the conditions for oak regeneration and promotes oak seedling and sapling growth. With the occurrence of adequate levels of natural oak regeneration, the economic cost of regenerating oak is reduced; improving the likelihood that landowners will manage for oak in the future (L1+). The two negative feedback loops link the spread of invasive oak pests and diseases to landowner oak management decisions (L2- and L3-) and serve to dissuade landowners from adopting oak management practices. Deer herbivory, invasive plant growth, and sugar maple regeneration were found by interviewees to negatively impact oak seedling and sapling growth; increasing the economic cost of oak regeneration and decreasing the likelihood that landowners will adopt oak management practices.

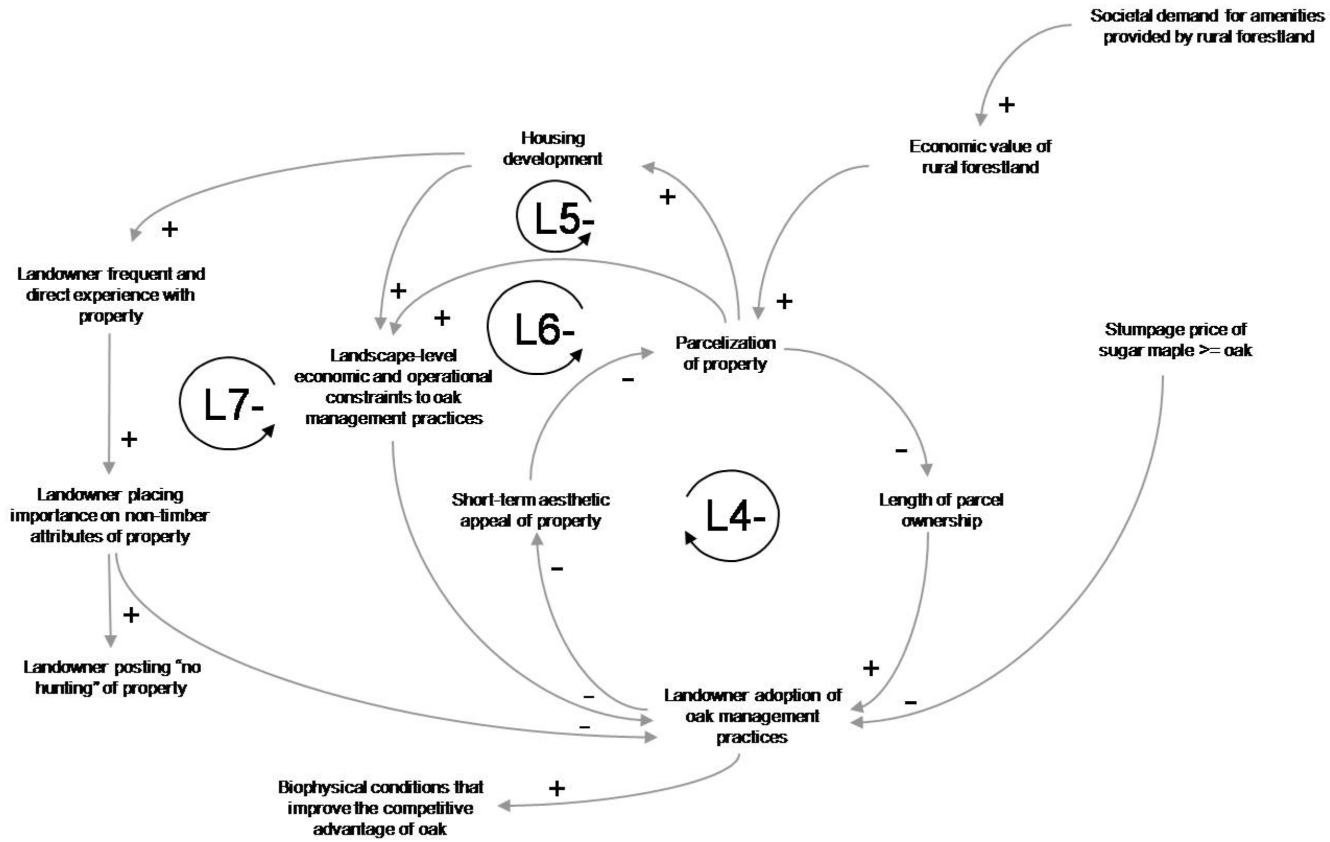

Fig. 5. The inhibiting effect of macro-level socioeconomic processes on landowner oak management decisions. The societal demand for forestland amenities was thought to have contributed to increasing the economic value and the likelihood that a landowner would choose to sell a portion of their land. Oak management practices were believed to result in a decrease in the short-term aesthetic appeal of the property, resulting in an increase in forestland parcelization, and a decrease in the length of parcel ownership. Short land tenure was thought to be associated with a lower likelihood that a landowner would choose to manage for oak, which requires a long-term perspective (L4-). Interviewees saw parcelization as directly and indirectly increasing landscape-level economic and operational constraints to oak management; decreasing the likelihood that landowners adopt oak management practices (L5- and L6). With an increase in exurban housing development, more landowners have direct and frequent contact with their forested property; resulting in an increase in the proportion of landowners placing importance on the non-timber attributes (e.g., aesthetics, hunting, privacy) of their lands (L7-). More landowners were also found to post their property against public hunting.

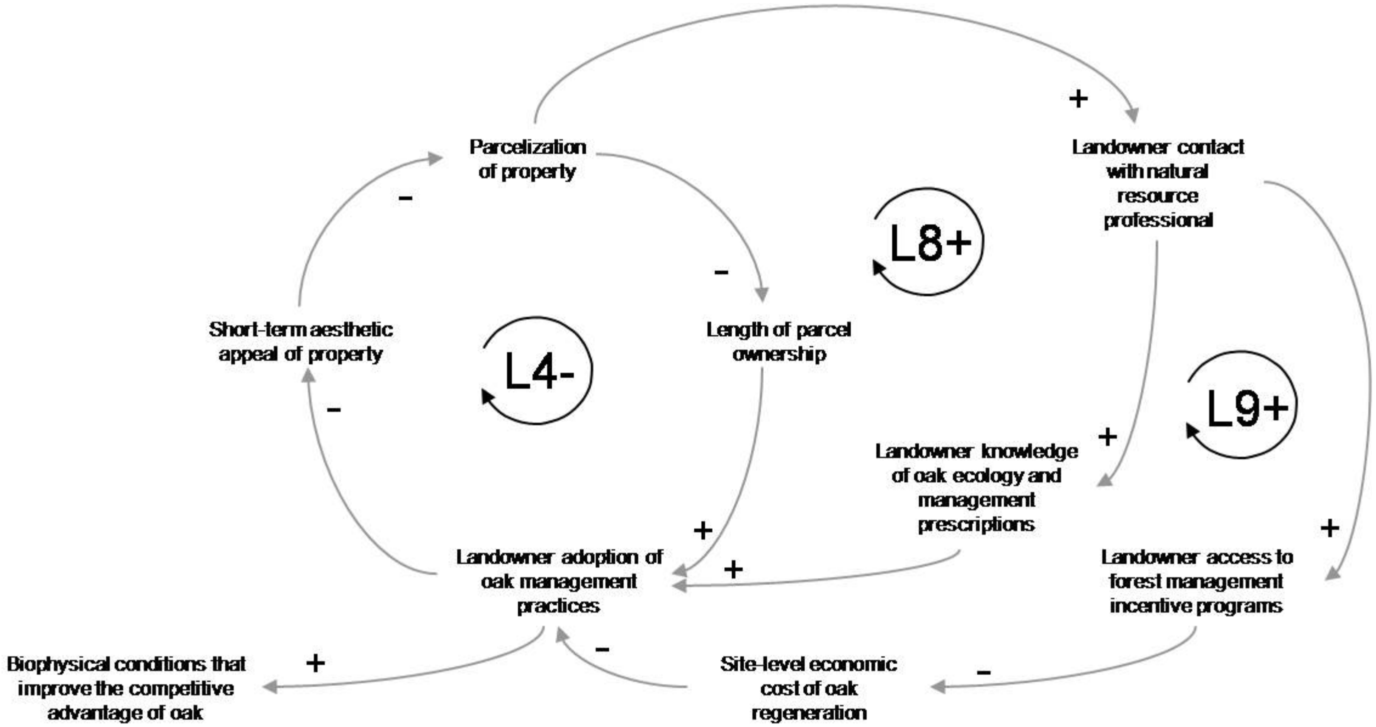

Fig. 6. Personal relationships and economic incentives promote oak-appropriate decision making. Interviewees described their interactions with private landowners as increasing landowners' knowledge of oak ecology and potential management prescriptions, as well as providing landowners access to forest management incentive programs. Both features directly and indirectly increase the likelihood that a landowner will adopt oak management practices (L8+ and L9+). Thus, parcelization can both decrease (L4-) and increase the likelihood that landowners adopt oak management practices.

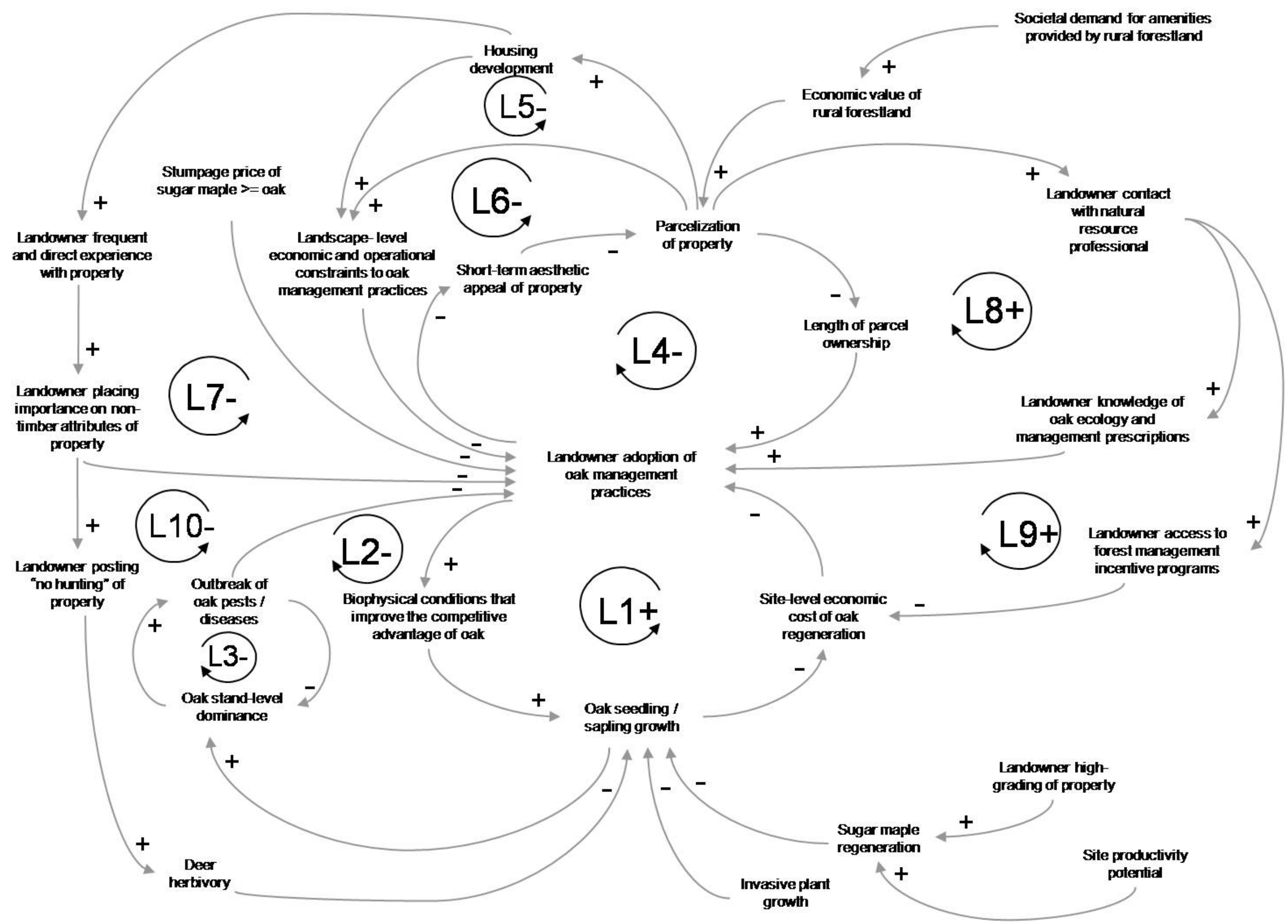

Fig. 7. Key variables, relationships, and feedbacks that influence the oak forest social-ecological system, from the perspective of regional change agents. Landowner adoption of oak management practices is central to the oak system and is the key variable connecting the ecological, social, and economic features of the system. Other important connections occur among system variables. For example, several of the interviewees linked the decline in public hunting of privately-owned lands to an increase in deer herbivory (L10-), connecting human behavior to a main ecological factor inhibiting landowner adoption of oak management (Fig. 4).

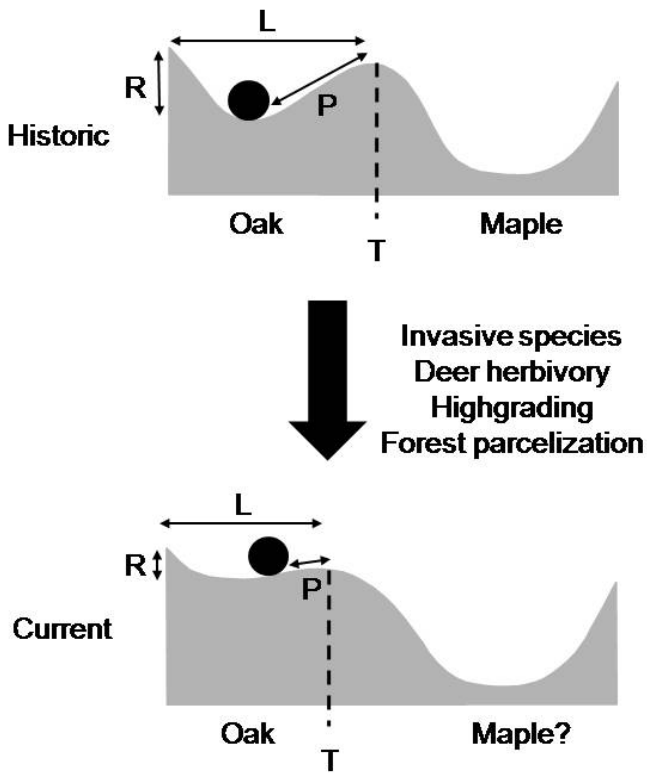

Fig. 8. The stability domains and landscape of the historic and current forest landscape in the Driftless Area of the Midwest, as portrayed through a ball and cup heuristic (adapted from Nowacki and Abrams 2008). The state of the system is the ball and the stability domains are represented as the cups (i.e., oak and maple). The stability landscape is composed of one or more domains. The transition between domains occurs where the conditions in the system reach a critical level or the system threshold (T). Overall system resilience, or ability of the system to retain the same structure and function, is influenced by: system resistance (R) to change; system latitude (L), or the maximum amount that the system can change before reaching a threshold, or system latitude (L); and the precariousness (P), or nearness to a threshold. The current oak system has decreased overall resilience to change due to a combination of ecological, economic, and social drivers, with a potential shift to a stability landscape dominated by maple or uncertain and novel stability domains.

APPENDIX 1

Example interview questions, including potential probing questions to further clarify interviewees' responses

Interview Question	**Probing / Clarifying Question**
What is your role as a natural resources professional?	• How long have you been in this profession? • In what area of the study region do you work?
What kinds of changes have you seen to the forest resources in your region?	• What kinds of changes have occurred to the forested landscape / within forest stands / oak forests / privately owned forests?
What are your main concerns about the forest resources in your region?	• What are your main concerns about oak forests in your region? • What are your concerns regarding state-owned land / privately-owned forests?
In your experience with private landowners, what concerns do landowners have about their forests?	• What kinds of interactions do you have with private landowners? • For what reasons do private landowners seek your advice?
What do you think are the main threats to oak regeneration in your region?	• What types of management recommendations are made to address these threats? • Do we have enough information to address the threats to oak regeneration, and if not, what is needed?
What impact do you think invasive plants and shrubs have on forests in your region?	• What invasive plants and shrubs are important in your region? • What types of management recommendations are made to combat invasive plants and shrubs?
What would you prefer the forests to look like in 50 to 100 years?	• What would you prefer the oak forests to look like in 50 to 100 years? • How can we realize this vision?

APPENDIX 2

Examples of some of the main components, processes, thresholds, and uncertainties of the oak social-ecological system, as described by regional natural resource professionals. These system features are categorized as either ecological or social/economic in nature and vary in the scale at which management and/or policy mechanisms are or could be used to address them. Example quotations are given to illustrate each feature (pseudonyms are used to protect interviewees' identities).

Key System Component or Process	Type of Issue	Management/ Policy Scale	Example Quotation
Deer herbivory[1]	Ecological	Site-level, multi-parcel, and regional	*[Deer herbivory] has gone ballistic. . . . There are a lot of woods that you can't find any tree younger than 20 years of age. And there are just browse lines on the edge of the woods. Talk about an oak regeneration problem! That's an enormous problem for Northeast Iowa. It's the number one culprit; I'm 100% convinced of that. It's not just shade and succession. . . . The bottom line is, let's say if you look at the deer pressure on a scale of 1 to 10; 10 being the worst. Well, you could probably just plant seedling walnut, cherry, ash, and spruce; if it was like a 7 or an 8, you could get by with certain things. But we're going to have to get that herd down to a 4 to grow oak again. To really be able to grow oak consistently, because [the deer are] selectively browsing [oak].* —Tim, a public forester for over 10 years
Spread of invasive oak pests and diseases[1,2]	Ecological	Site-level, multi-parcel, regional, national, and global	*My main concern right now is what's on the horizon with gypsy moth and emerald ash borer coming at us. I think that too is going to change the face of the Driftless Area. Gypsy moth is going to rage through; it's going to take—probably the first go-around—it's going to take all the unhealthy trees, trees on poor aspects. Between that and black oak, our south slope red oak stands could be decimated. The oak wilt is going to get them, or gypsy moth is going to defoliate them three years in a row.* —Bob, a veneer buyer in the region for nearly 20 years
Spread of invasive plant species[1,2]	Ecological	Site-level, multi-parcel, regional, national, and global	*Now the number one problem we've got . . . is the invasive species. European buckthorn has completely changed what we're doing either for post-treatment or follow-up treatment. It's the primary thing we have to kill. It gets so bad there even sugar maple can't regenerate. And it's incredibly expensive.* —Leo, a consulting forester for over 20 years
Advanced sugar maple regeneration[1]	Ecological	Site-level, multi-parcel, regional	*And with red oak, with this amount of deer herd that we have, and with the amount of competition that's generated, it's next to impossible to get red oak to regenerate in this hardwood stand. Unless you do very intensive management. And then what's the point if you've already got basswood and maple encroaching. You can manage until you're blue in the face and it's still going to encroach!* —Leo, a consulting forester for over 20 years

[1]Described as a key system threshold; once a critical level is reached, management practices are ineffective or cost prohibitive.

[2]Described as a critical uncertainty in the system. Natural resource professionals were uncertain about the future trajectory of these components or processes or unsure about how or if management and policy mechanisms could be implemented to address these issues

Key System Component or Process	Type of Issue	Management / Policy Scale	Example Quotation
Landowner adoption of oak management practices	Social/ Economic	Site-level, multi-parcel, regional	*A lot of landowners when they write their [management plans] . . . they'll say, 'I want to manage for oak.' Well, when you talk to them and you find out about it, they really mean, 'I don't really want to manage for oak, I don't want to manage another oak stand, but I really like the oak trees I have. So I really want to keep these oak trees.' But they're not willing to go through the expense, and the time, and the effort to actually try to bring back oak.* —Dan, a consulting forester for nearly 10 years
Site-level economic cost of oak regeneration	Social/ Economic	Site-level	*In these direct [oak] seedings, we usually get really good germination of your oaks, red and bur anyway, but the deer usually get them, or the rabbits. What they've gone to doing is basically leaving out the acorn component and . . . going in the following spring and planting 10-20 good sized oak and then caging them, a wire cage. Although it's a lot of work and it gets spendy, it might be the way we'll have to go to guarantee oak until the deer herd is thinned out. . . . But that costs almost $10 a tree.* —Dale, a logger and contract forester for over 30 years
Forest parcelization and exurban housing development[1,2]	Social/ Economic	Site-level, multi-parcel, regional, and national	*The other change is that the forest is being fragmented. . . . .Because the value of recreational land right now, it's worth more than crop land. People are paying $3,000 dollars an acre for a place to hunt. People are selling off that woods from the farm, and it's fragmenting the landscape.* —Grant, a public forester for nearly 30 years
Short-term aesthetic appeal of property	Social/ Economic	Site-level	*During the harvest, it's going to be ugly, no doubt. For ten years after the harvest, even if you do everything right, it's going to be so thick you can't walk through it. So it's not real enjoyable. And then after 15 or 20 years it starts to kind of become a little easier to get through.* —Rich, a consulting forester for nearly 20 years
Landowner placing importance on non-timber attributes of property	Social/ Economic	Site-level	*I see a lot of building going on out in the timber and I hate to see that too. I think that takes away from the timber resource. . . . They want some recreation ground. They want a park. . . . They've got resources available, financial resources they can actually build a house and [they think], 'Look, this is great, we can live out in the park.' Parks are not managed for timber very well, they're there for looks; they're not there for timber management that usually involves some sort of cutting, disturbances we're talking about. And people that live out there, well they don't want to disturb it…They don't want to mess it up. That's makes it tough to do some sort of management activity.* —Todd, a consulting forester for over 10 years

Key System Component or Process	Type of Issue	Management/ Policy Scale	Example Quotation
Landowner posting "no hunting" of property	Social/ Economic	Site-level, multi-parcel, regional	*A recreational buyer . . . the first thing they do is slap "no hunting" signs all over their boundaries. . . . One of my clients . . . he lived there most of his life and . . . he said when he was a kid he could count 23 different farms in this area that he could hunt. And he says now there's only one farm of those 23 he's got any permission to hunt on, and all the others have been locked up.* —Tim, a public forester for over 10 years
Stumpage price of sugar maple >= oak	Social/ Economic	Regional, national, and global	*But since there was a lot of over mature [oak] timber, a lot of these woods had maple-basswood understory. When you finally took the bigger oak, it released the maple-basswood, so now we've got some more pure stands of maple-basswood. Which, in our industry, the way we're looking at it now with hard maple being excellent, even more valuable than oak, and basswood kind of a medium grade value wood, we're going to manage for those timbers.* —Paul, a sawmill owner for over 25 years
Landscape-level economic and operational constraints	Social/ Economic	Regional, national	*Say you have 30 contiguous acres of woods and if it is owned by one property owner, say it's a nice red oak stand for the most part. If that one landowner . . . he would be much more apt to be able to carry out proper silviculture on it, carry out a harvest on it, regenerate the oak. That same 30 acre parcel is now six landowners of five acres apiece. The likelihood of being able to get that harvested in the same way is gonna be a lot more difficult, because…you have six different landowners and…for them all to have the same interest and same goals, both short- and long-term, is not always the case. . . . It kind of takes away some of the managing based on what the actual resources are. It takes away some tools from sound forest management. . . . It brings more social or human factors into…[how] the actual management is carried out on that property.* —Sam, nearly 10 years as a public forester
Landowner contact with natural resource professional	Social/ Economic	Site-level, regional	*Probably the biggest challenge with the landowners is getting them to call. Once, if they call, then the chances of them doing something are pretty high. Once you start working with them, most people, when they see what needs to be done in their woods, everybody's willing to do something. The cost-sharing is a big benefit in that. . . . The cost of doing this stuff, if it gets too prohibitive, it's going to prevent people from [managing their forest].* —Rob, a public forester for over 15 years
Landowner selective removal (high-grading) of individual, high value trees	Social/ Economic	Site-level, regional, national	*A lot of the harvesting that occurs…is at the whim of the owner and the logger. And what typically happens still is a high-grade down to a certain [tree] diameter limit, and in a lot of cases that just tends to promote further conversion to, if we're lucky here, maybe northern hardwoods—sugar maple, basswood, ash—or if you're unlucky, it's elm, hickory and box elder. So we have a wholesale conversion of former oak stands to something else.* —Jake, a public forester for over 30 years

CHAPTER 5.
FOREST CHANGE IN THE MIDWESTERN DRIFTLESS AREA: FROM PREFERRED TO UNDESIRABLE FUTURE

A paper to be submitted to the *Northern Journal of Applied Forestry*

T. G. Knoot, L. A. Schulte, B. Palik, and M. Hatfield

ABSTRACT

The current state of oak systems in the midwestern and eastern U.S. may be nearing critical thresholds; if reached, restoration may become especially challenging, if not impossible. An understanding of spatial variation in oak forest change could improve the efficacy of intervention strategies. Using Forest Inventory and Analysis (FIA) inventories, we evaluated changes in the composition of timberland across subsection ecoregions in the Driftless Area of the Midwest over a 20-30 year time period. We identified an overall decrease in the extent of the oak-hickory forest type group and a slight increase in sugar maple-basswood and elm-ash-cottonwood timberland. There was spatial variation in these trends, however, with some pronounced differences across adjacent state boundaries. We used nonmetric multidimensional scaling (NMS) to identify pathways of change for each subsection and found that the composition of timberland has become more similar over time. In addition, our analyses revealed less variation in the age of oak-hickory timberland; currently, the majority of stands range 45-95 years of age. Our findings corroborate qualitative evidence from interviews with natural resource professionals from the region and offer further information on the potential for forest conversion to an undesirable future, as identified as a source of concern by the professionals. The variation in forest change across state boundaries suggests the importance of state-level socioeconomic and policy factors on forest conditions and thus the potential for a targeted and timely approach to promoting preferred pathways of change.

INTRODUCTION

Oak-dominated forests of the midwestern and eastern United States are experiencing substantial changes, as the combination of natural succession and human-related factors have created conditions that typically favor more mesic, broad-leaved forest types (termed the "mesophication" of the forests; Nowacki and Abrams 2008). Oaks (*Quercus* spp.) provide important resources for a variety of plants and animals (McShea and Healy 2002, Rodewald and Abrams 2002, Fralish et al. 2004) and are highly valued by society for economic and cultural reasons (Starrs 2002). Prior to Euro-American settlement, the disturbance of oak woodlands by periodic fire was common (Abrams 1992), and early- to mid-successional, fire-adapted oak forests maintained a competitive advantage over later-successional forest types. However, spatial variation in fire disturbance maintained landscape-level heterogeneity of ecosystem types (Nowacki and Abrams 2008). Changing land ownership patterns and management decisions since settlement have contributed to altered disturbance regimes and early- to mid-successional communities have subsequently dwindled in extent (Williams 1989, Askins 2001). Presently, fire suppression and widespread selective harvesting (often high-grading) of deciduous forest stands have contributed to within-stand and landscape-level forest homogeneity, favoring later-successional forest types (Kittredge et al. 2003).

Regional forest managers seeking to promote oak regeneration face combined ecological, economic, and social issues that inhibit the efficacy of typical oak management prescriptions, such as clearcutting and prescribed fire (Chapter 2), especially since the majority of forestland in the U.S. is privately owned (Butler and Leatherberry 2004). Periodic disturbance is crucial to the persistence of oak (Johnson et al. 2002), but management aimed at maintaining or restoring early- to mid-successional types may appear counterintuitive to conservation-minded landowners (Askins 2001). In addition, current trends in forest parcelization and land tenure in the U.S. (Best and Wayburn 2001) reduce the likelihood that landowners will hold the long-term land management perspectives that are required for perpetuating oak (Chapter 4).

The current state of oak systems in the midwestern and eastern U.S. may be nearing critical thresholds; if reached, restoration may become especially challenging, if not impossible (Chapter 4; Nowacki and Abrams 2008). Social factors, including but not limited to forest parcelization and short land tenure, constrain landowner decision making regarding oak at multiple spatial scales. Ecological drivers of forest change (e.g., level of oak regeneration, soil moisture availability) vary over space and time (Iverson et al. 1997, Nowacki and Abrams 2008). There are a variety of policy mechanisms, including economic incentives, which could be used to encourage landowners to conserve oak (Fischer and Bliss 2008). But a spatially targeted approach—one that identifies regions where forest change is most rapid and pronounced—would most effectively utilize the limited funding devoted to landowners assistance.

The purpose of our research was to evaluate forest change, and specifically oak-hickory forest change, over the last 20 years across the Midwest Driftless Area (Fig. 1). We conducted a preliminary qualitative assessment of the state of oak forests and trajectory of forest change through interviews with regional natural resource professionals. Most professionals noted a widespread lack of oak regeneration and associated increase in sugar maple (*Acer saccharum* Marsh.), but noted variation in this trend across the landscape and over time. Sugar maple regeneration was often deemed economically beneficial by these professionals (Chapter 4), whereas shifts to tree species compositions that included ash (*Fraxinus* spp.) and elm (*Ulmus* spp.) were regarded as less desirable (Chapter 4). A quantitative assessment of the spatial variation in forest change across the region could promote dialogue on preferred alternative futures for the forest resources, how to attain them, and the development of targeted policies to assist landowners.

METHODS

Study area

The Driftless Area, also known as the Paleozoic Plateau or Blufflands, is roughly 50,000 km^2 in size in size and includes portions of Minnesota, Wisconsin, Iowa, Illinois (Fig. 1). This region is considered part of the humid, hot continental climate division, and is contained within the eastern deciduous forest province (Bailey 1983). Historically, the Driftless Area was composed of diverse land cover types including tallgrass prairie, bur oak (*Quercus macrocarpa* Michx.) savanna, oak-hickory and sugar maple-basswood forest (Albert 1995). The landscape is presently a mix of agricultural lands and deciduous forest (Prior 1991, Albert 1995).

Forest inventory and analysis data

We evaluated forest change in the Driftless Area using the U.S. Forest Service Forest Inventory and Analysis (FIA) program data. The FIA monitoring program was mandated by Congress in the McSweeney-McNary Forest Research Act of 1928 and amended by the

Forest and Rangeland Renewable Resources Planning Act of 1974 with the goal of regularly assessing the state of the nation's public and private forestlands (Smith 2002). For 70 years, each state's forestland has been surveyed on a cycle of about every 8-15 years; the dates for each survey varied by state (Gillespie 1999). In accordance with specifications set forth in the Farm Bill of 1999, the FIA program began surveying 20% of the survey plots in each state each year, completing a full survey of the plots over a five-year period, providing timely information for managers and policy makers (USDA Forest Service 2007). These surveys offer a wealth of information for identifying landscape-level changes in forest conditions over time (e.g., Smith et al. 2004).

We compared FIA data collected in the fourth and fifth periodic surveys (1977–1990) to the data collected through annual surveys (completed from 2002–2006). The earliest periodic inventories for which digital data were available were: Iowa, 1990; Illinois, 1985; Minnesota, 1983; and Wisconsin, 1977.

Unit of analysis

We evaluated forest conditions within subsection-level ecosystems that comprise the Driftless Area (Fig. 1). Subsections are one ecological unit within the U.S. Forest Service's hierarchical framework (Cleland et al. 1997, McNab et al. 2007). Similar patterns in climate, physiography, geologic substrate, and potential natural communities designate subsection boundaries (Cleland et al. 1997). In the Driftless Area, subsections range between about 3,000 to 21,000 km^2 in size. Because some subsections were represented in more than one state, and survey dates varied by state, our unit of analysis is the subsection by state. The number of FIA inventory plots collected per unit of analysis ranged from 230 to 15,014 in the periodic inventories, as compared to 1,529 to 10,184 in the more current, annual forest inventories (Table 1).

Analysis methods

We used a combination of tabular, graphical, and map-based representations of forest conditions, focusing on the four most prominent forest type groups in the region: oak-hickory, maple-basswood, elm-ash-cottonwood, and aspen-birch groups (Fig. 2). We evaluated changes in the stand-size classes for each forest type group. Stand size was represented by three main classifications, related to the majority of live trees measuring a particular dimension: (1) large diameter hardwood trees > 11 inches (softwoods measuring 9 inches) diameter at breast height (dbh); (2) medium diameter hardwood trees 5–10.9 inches dbh (softwoods 5–8.9 inches dbh); and (3) small diameter trees < 5 inches dbh (USDA Forest Service 2007). We also assessed the change in oak-hickory timberland stand age, recorded in 10-year age classes.

Nonmetric multidimensional scaling (NMS) was used to further evaluate pathways of change among the forest type groups and size classes over the period of the two forest inventories. The NMS ordination technique, which uses a set of ranked distances (dissimilarities), is appropriate for data sets that include zeros (McCune and Grace 2002), such as ours. We included the proportion of timberland within each of the above forest type groups and the proportion of forestland within the three size classes of the oak-hickory, maple-basswood, and elm-ash-cottonwood groups. The stand size classes for the aspen-birch group were not included in the ordination analysis because this group was not recorded in some stand size classes for over half of the subsections (Table 2). We excluded the subsection LeIL from our evaluation due to the small number of non-zero plots in the previous and current inventories (two plots in the periodic survey and 5 plots in the annual survey) and the large amount of error associated with these estimates (Appendix 1).

The NMS analysis was performed using PC-ORD (McCune and Mefford 1999) and the Bray-Curtis (Sorensen) distance measure. We used an automated search with a random starting configuration, 40 iterations with the real data, and at least 50 runs to evaluate stability. Preliminary analyses were run with up to six dimensions, but a substantial amount of stress reduction was achieved with the first three axes. Our final configuration had a final stress of 4.80 and instability of 0.00001 based on 77 iterations, and explained a substantial amount of the variation in the data ($r^2 = 0.83$). The low level of stress in this configuration indicates that there is little risk of drawing false inferences (McCune and Grace 2002).

RESULTS

Timberland area in the Driftless area has increased in nearly all subsections (Table 2). The Kickapoo-Wisconsin River Ravines (Ld) subsection of Wisconsin (Table 2) had the highest proportion of land designated as timberland (43%) in the previous inventory (Table 2), but in contrast to the trend seen in other subsections, timberland decreased (< 2%) between inventories in this subsection (Table 3). The other subsections increased in timberland by less than 10% over the last 20–30 years (Table 3). In general, the proportion of timberland is presently highest the Wisconsin portion of the Driftless Area and along the Mississippi River (Fig. 2).

While trends in overall timberland cover were fairly consistent, we found wide variation across the region within forest cover types and stand size classes (Table 3). Overall, the extent of oak-hickory has decreased in the region (-4.2%; Fig. 3), but varied from -16.2% to +5.6% by state-level subsections (Table 3). Subsections in Minnesota and Illinois experienced the greatest loss of oak-hickory, while both Iowa subsections experienced an increase in this forest type group (Fig. 4). Oak-hickory also declined in three subsections in Wisconsin (Fig. 4). Overall, roughly 70% of the Driftless Area experienced a decline in the extent of oak-hickory timberland since the previous inventories (Table 3). Although the Kickapoo-Wisconsin River Ravines (Ld) subsection of Wisconsin experienced an overall increase in oak-hickory timberland (due mostly to an expansion of oak-hickory within the medium diameter size class; Table 3), this subsection was found to have the most substantial decrease in the area of small diameter oak-hickory (-8.4%; Table 3, Fig. 4). In all but the Iowa subsections of the Driftless Area, there has been a decline (or no change in the case of the Illinois subsection) in the proportion of oak-hickory timberland in the small diameter stand size class (Fig. 4).

In the aggregate, the extent of maple-basswood timberland has slightly increased throughout the region (Fig.3), with approximately 60% of the area experiencing an increase in maple-basswood (Table 3). At the subsection scale, subsections west of the Mississippi River and immediately adjacent to the river experienced an overall increase in maple-basswood, while the eastern-most subsections in Wisconsin showed decreasing proportions of this forest type (Fig. 4). Conversely, we found that the acreage of small diameter maple-basswood timberland has decreased in most subsections, especially in the Kickapoo-Wisconsin River Ravines (Ld) subsection of Wisconsin (-12.6%; Table 3, Fig. 4).

As timberland has expanded throughout the region, the loss of oak-hickory appears to have been compensated by an overall increase in the elm-ash-cottonwood forest type (Fig. 3), including in two subsections of Wisconsin (Kickapoo-Wisconsin River Ravines-Ld and

Mineral Point Prairie-Savannah-Le) where this forest type was not recorded in previous inventories (Table 3, Fig. 4). In particular, the medium diameter size class of this forest type has increased in all subsections except the Mississippi-Wisconsin River Ravines (Lc) subsection in Illinois; the response of large and small diameter size classes have been variable in the region (Table 3). In contrast, the aspen-birch forest type has declined in all the subsections where it was recorded in previous inventories. The exception is the Kickapoo-Wisconsin River Ravines (Ld) subsection of Wisconsin, but aspen-birch was only recorded in the current inventory and not in the previous one (Table 2).

The three ordination axes from the NMS explained a substantial amount of the variation (r^2= 0.83) in the data and identified shifts in forest composition and direction of change among the subsections (Fig. 5). Most of the variation was explained by axis 3 (r^2= 0.44); axis 1 and 2 explained the same amount of variation (axis 1: r^2=0.20; axis 2: r^2=0.20). Axis 1 represents the dichotomy between the proportion of elm-ash-cottonwood timberland in the large diameter size class and the proportion of oak-hickory timberland in the small diameter size class in a subsection (Table 4, Fig. 5). Axis 2 and 3 identify similar trends in the data, highlighting the relationship between the proportion of oak-hickory and maple-basswood in a subsection (Table 4).

In general, our findings from the NMS corroborated the results from our tabular and map-based assessments. The prominent trends include the general shift in timberland composition towards an increase in elm-ash-cottonwood forests and decline in oak-hickory (Figs. 3–5). However, the portions of the Mississippi-Wisconsin River Ravines (Lc) subsection in Iowa and Illinois and the Western Paleozoic Plateau (Lf) subsection of Iowa diverge from this pattern (Fig. 5). We also noted that subsections with relatively high proportions of oak-hickory large diameter timberland have experienced an increase in maple-basswood dominance, specifically an increase in small diameter maple-basswood timberland (Table 4, Fig. 5). In contrast, two subsections in Wisconsin (La and Ld) and one subsection in Iowa (Lc) with a relatively low dominance of oak-hickory in previous inventories have shown a decrease in maple-basswood and associated increase in oak-hickory (Fig. 5). The subsections appear to be converging towards more similar timberland compositions (towards the center of the ordination space) (Fig. 5).

Our assessment of oak-hickory stand age over time revealed that 33% of the oak-hickory timberland in the region in previous inventories was between 0 and 25 years or over 105 years of age. In contrast, the young and old stands in current inventories comprised only 10% of the total oak-hickory timberland in the region. As an example, there is less variation in stand age in the Wisconsin portion of the Mississippi-Wisconsin River Ravines (Lc) subsection, with the majority (88%) of oak-hickory stands ranging from 45–95 years of age (Fig. 6).

DISCUSSION

Our evaluation of forest change in the Driftless Area of the Midwest over a relatively short time period suggests a subtle shift towards a more homogeneous age structure for oak-hickory timberland and greater similarity in timberland composition across subsections. Our findings parallel insights gained from stand and landscape-level forest surveys in the midwestern and eastern U.S., where understory competition (Lorimer et al. 1994)—often facilitated by widespread and dispersed highgrading (Kittredge 2003) and a decrease in fire disturbance (Abrams 1992)—and white-tailed deer (*Odocoileus virginianus*) herbivory (Rooney and Waller 2003) have been suggested as contributing to a decline in oak regeneration and stand- and landscape-level homogenization of species. Our study contributes to a richer picture of recent forest change in the Midwest—complementing qualitative social data collected from the study region—and underscores the potential influence of human drivers of forest change at broad spatial scales.

Although we did not experimentally evaluate the causal factors of forest change, data collected through interviews with natural resource professionals from the Driftless Area are consistent with our findings from the quantitative evaluation of forest change and provide depth of understanding about potential regional drivers of forest change (Chapter 4). Most interviewees, many of which have lived and worked in the region for over 20 years, noted very little oak regeneration, an increase in maple-basswood regeneration, and an overall increase in tree species that they considered less preferable (Chapter 4). To account for these changes, the interviewees suggested that highgrading continues to be a dominant timber harvesting practice. Many noted that natural resource professionals are involved with only a fraction of the timber harvesting events that take place on private lands; thus, they believed that without their long-term ecological and silvicultural perspective, short-term economic motivations were instead driving private landowner management decisions (Chapter 4). In addition most of the professionals have found deer herbivory to have a dramatic effect on oak regeneration, noting that deer prefer oak species over others (Chapter 3). The combined effects of highgrading and deer herbivory may account for the decline in the extent of oak-hickory and shift towards maple-basswood and elm-ash-cottonwood. Highgrading, where only high quality and economically valuable trees are selectively removed from a forest stand, usually results in small gap openings that do not provide adequate light requirements for oak establishment (Johnson et al. 2002); shade-tolerant species often gain a competitive advantage in this type of environment. In addition, even if adequate light is provided through intensive harvesting methods, advanced oak regeneration is needed before the harvesting event so that the stand does not shift even more rapidly to other forest types (Abrams and Nowacki 1992). Chronic deer herbivory of oak seedlings could inhibit natural oak regeneration at a site (Rooney and Waller 2003).

While a shift towards maple-basswood and away from oak-dominated timberland could have ecological ramifications, such as a decrease in songbird diversity (Rodewald and Abrams 2002), we found that many natural resource professionals viewed an increase in the extent of the maple-basswood forest type as advantageous given the current strong timber market for sugar maple (Chapter 4); a shift towards the elm-ash-cottonwood forest type group was considered nondesirable. Through our quantitative analysis of forest change, we found a slight increase in the overall extent of maple-basswood timberland (especially in subsections in Iowa, Illinois, and Minnesota), but a decline in the proportion of small diameter maple-basswood (although not as much as the extent of small diameter oak-hickory) through much of the region (Fig. 4), suggesting that this forest type group may contract in the future. In addition, recent climate change models suggest a decline in suitable conditions for sugar maple in our region (Prasad et al. 2007). Instead, species within the elm-ash-cottonwood forest type group may have a stronger future in the Driftless Area; however, the likely spread of the emerald ash borer (*Agrilus* planipennis) (Poland and McCullough 2006) and continued impact of Dutch elm disease on mature American elm

(*Ulmus americana* L.) trees (Parker and Leopold 1983) could restrict the continued expansion of the main species comprising this forest type.

Regional variation in forest composition is often attributed to environmental factors such as changes in soil moisture, topography, and climate (e.g., Iverson et al. 1997, Fuller et al. 1998). However, since Euro-American settlement, widespread human alterations of historic forest disturbance regimes have caused substantial landscape-level changes forest composition (Fuller et al. 1998, Hessburg et al. 2005, Schulte et al. 2007). The subsection-level boundaries that we used in our study indicate regions with similar environmental conditions (Cleland et al. 1997). Although the length of time to evaluate forest change varied by state, we expected that the direction of forest change would be similar throughout subsections, despite intersecting state boundaries. However, we encountered some abrupt changes in the trajectory of forest change across state boundaries (Fig. 4), a finding which underscores the likely influence of socioeconomic and policy forces on forest change. For example, change in timberland composition in the portions of the Western Paleozoic Plateau (Lf) and Mississippi-Wisconsin River Ravines (Lc) subsections in Minnesota and Iowa appears to be dissimilar, with the Iowa portions experiencing increases in the area of oak-hickory, including oak-hickory of the small diameter size class. The Minnesota portions of the above subsections have concomitantly experienced the greatest decline in the area of oak-hickory timberland (Fig. 4). The Minnesota portions of these subsections also differ from Iowa in the overall increase in elm-ash-cottonwood (Fig. 4).

CONCLUSIONS

Within a relatively short time period, oak-hickory timberland in the Driftless Area of the Midwest has experienced a decline in proportion of young and old stands. In addition, the trajectory of forest change reveals that oak-hickory timberland is being replaced by both shade-tolerant forest type groups and less desirable timber species, such as ash (*Fraxinus* spp.) and elm (*Ulmus* spp.). Spatial variation in the pattern of change was notable, especially within-subsection differences across state boundaries. This pattern suggests that socioeconomic and policy factors have likely played a role in driving forest change during this relatively short time period of analysis. Through previous interviews with natural resource professionals from the region, we found that—while oak-hickory is still a highly valued forest type—the social and economic challenges associated with managing for oak has led many professionals to welcome a shift towards shade-tolerant species such as maple (Chapter 2). However, our quantitative assessment of change, combined with recent climate change projections, suggests that shifts towards less desirable species may be more likely in some portions of the region. Therefore, dialogue among key forest stakeholders is needed to determine appropriate, targeted, and timely mechanisms that can halt and potentially reverse shifts towards undesirable forest system conditions.

ACKNOWLEDGEMENTS

This research was supported by funds from the USDA Forest Service – Northern Research Station and Iowa State University. Project guidance and helpful review comments were provided by N. Grudens-Schuck, J. Miller, and M. Rickenbach. T. Knoot was a research fellow with the U.S. EPA – STAR Graduate Fellowship Program. EPA has not officially endorsed this publication and the views expressed herein may not reflect the views of EPA.

LITERATURE CITED

Abrams, M.D. 1992. Fire and the development of oak forests. *Bioscience* 42(5):346-353.

Abrams, M.D., and G.J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. *Bull. Torrey Bot. Club* 119:19-28.

Albert, D. A. 1995. *Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification.* USDA For. Ser. Gen. Tech. Rep. NC-178. 250 p.

Askins, R. A. 2001. Sustaining biological diversity in early successional communities: the challenge of managing unpopular habitats. *Wildl Soc. Bull.* 29:407-412.

Bailey, R.G. 1983. Delineation of ecosystem regions. *Environ. Manag.* 7:365-373.

Best, C., and L.A. Wayburn. 2001. *America's private forests: Status and stewardship*. Island Press, Washington, D.C. 268 p.

Butler, B.J., and E.C. Leatherberry. 2004. America's family forest owners. *J. For.* 102(7):4-9.

Cleland, D.T., P.E Avers, W.H. McNab, M.E. Jensen, R.G. Bailey, T. King, and W.E. Russell. 1997. National hierarchical framework of ecological units. P. 181-200 in *Ecosystem* *management applications for sustainable forest and wildlife resources,* Boyce, M. S., and A Haney (eds.). Yale University Press, New Haven, CT.

Fischer, A. P., and J. C. Bliss. 2008. Behavioral assumptions of conservation policy: conserving oak habitat on family-forest land in the Willamette Valley, Oregon. *Conserv. Biol*. 22:275-283.

Fralish, J.S. 2004. The keystone role of oak and hickory in the central hardwood forest. Pages 78-87 in: *Upland oak ecology symposium: history, current conditions, and sustainability,* Spetich, M.A.(ed.). USDA For. Serv. Gen. Tech. Rep. SRS-73. 311 p.

Fuller, J.L., D.R. Foster, J.S. McLachlan, and N. Drake. 1998. Impact of human activity on regional forest composition and dynamics in Central New England. *Ecosystems* 1:76-95.

Gillespie, A. J. 1999. Rationale for a national annual forest inventory program. *J. For.* 97(12):16-20.

Hessburg, P. F., J. K. Agee, and J. F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras. *For. Ecol. and Manag.* 211:117-139.

Iverson, L.R., M.E. Dale, C.T. Scott, and A. Prasad. 1997. A GIS-derived integrated moisture index to predict forest composition and productivity of Ohio forests (U.S.A.). *Landsc. Ecol.* 12:331-348.

Johnson, P. S., S. R. Shifley, and R. Rogers. 2002. *The ecology and silviculture of oaks.* CABI Publishing, New York, NY.

Kittredge, D.B., Jr., A.O. Finley, and D.R. Foster. 2003. Timber harvesting as ongoing disturbance in a landscape of diverse ownership. *For. Ecol. and Manag.* 180:425-442.

McCune, B., and J. Grace. 2002. *Analysis of ecological communities.* MjM Software Design, Gleneden Beach, OR, 300 p.

McCune, B., and M. J. Mefford. 1999. *PC-ORD: multivariate analysis of ecological data,* vol 4.25. MjM Software Design, Gleneden Beach, OR.

McNab, W.H., D.T. Cleland, J.A. Freeouf, J.E. Keys, G.J. Nowacki, C.A. Carpenter. 2007. *Description of ecological subregions: sections of the conterminous United States* [CD-ROM]. USDA For. Serv. Gen. Tech. Report WO-76B. 80 p.

McShea, W.J., and W.M. Healy. 2002. Oaks and acorns as a foundation for ecosystem management. P. 1-9 in *Oak forest ecosystems: ecology and management for wildlife,* McShea, W.J. and W.M. Healy (eds.). The Johns Hopkins University Press, Baltimore, Maryland.

Nowacki, G.J., and M.D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. *Bioscience* 58:123-138.

Parker, G.R., and D.J. Leopold. 1983. Replacement of *Ulmus Americana* L. in a mature east-central Indiana woods. *Bull. Torrey Bot. Club* 110:482-488.

Poland, T.M., and D. G. McCullough. 2006. Emerald ash borer: invasion of the urban forests and the threat to North America's ash resource. *J. of For.* 104:118-124.

Prasad, A.M., L.R. Iverson., S. Matthews., M. Peters. 2007. *A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States* [database]. Northern Research Station, USDA Forest Service, Delaware, OH. Available online at http://www.nrs.fs.fed.us/atlas/tree; last accessed August 2, 2008.

Prior, J. C. 1991. *Landforms of Iowa*. University of Iowa Press, Iowa City, Iowa. 154 p.

Rodewald, A.D., and M.D. Abrams. 2002. Floristics and avian community structure: Implications for regional changes in eastern forest composition. *For. Sci.* 48(2):267-272.

Rooney, T.P., and D.M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *For. Ecol. Manag.* 181:165-176.

Schulte, L.A., D.J. Mladenoff, T.R. Crow, L.C. Merrick, and D.T. Cleland. 2007. Homogenization of northern U.S. Great Lakes forests due to land use. *Landsc. Ecol.* 22:1089-1103.

Smith, W. B. 2002. Forest inventory and analysis: a national inventory and monitoring program. *Environ. Pollut.* 116:S233-S242.

Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2004. *Forest resources of the United States, 2002.* USDA Forest Service Gen. Tech. Rep. NC-241. 137 p.

Starrs, P.F. 2002. Perspectives on cultural values of California oaks. P. 21-30 in: *Proc. of the fifth symposium on oak woodlands: oaks in California's changing landscape,* Standiford, R.B, D. McCreary, and K.L. Purcell (compilers). USDA Forest Service Gen. Tech. Rep. Gen.. PSW-GTR-184. 10 p.

US Forest Service. 2006. *Forest inventory and analysis DataMart*, version 3.0. Available online at http://fiatools.fs.fed.us/fiadb-downloads/fiadb3.html; last accessed August 2, 2008.

US Forest Service. 2007. *Forest inventory and analysis database: Database description and users guide*, version 3.0. National Forest Inventory and Analysis Program, USDA For. Serv. 230 p.

Williams, M. 1989. *Americans and their forests: A historical geography*. Cambridge University, Cambridge, Massachusetts. 599 p.

Table 1. Subsections within the Driftless Area of the Midwest, including the proportion of the land that is considered timberland, the total number of US Forest Service Forest Inventory and Analysis (FIA) plots for the previous and current inventories, and the number of plots that contained timberland (non-zero plots).

			Previous Inventories[a]			Current Inventories[b]		
Subsection by State	Subsection Name	Km²	% Timberland	Total Plots	Non-zero Plots	% Timberland	Total Plots	Non-zero Plots
LcIA	Mississippi-Wisconsin River Ravines	3600	26	510	71	30	1529	51
LfIA	Western Paleozoic Plateau	4416	15	472	50	20	1529	47
LcIL	Mississippi-Wisconsin River Ravines	1151	16	359	11	21	3700	10
LeIL	Mineral Point Prairie-Savannah	439	8	230	2	24	3666	5
LaWI	Menominee Eroded Pre-Wisconsin Till	3741	27	2779	98	30	2388	118
LbWI	Melrose Oak Forest and Savannah	6947	37	5128	262	43	3274	310
LcWI	Mississippi-Wisconsin River Ravines	11059	37	5136	357	40	3114	477
LdWI	Kickapoo-Wisconsin River Ravines	3235	43	5321	125	41	1587	135
LeWI	Mineral Point Prairie-Savannah	5051	9	2757	43	13	2123	77
LcMN	Mississippi-Wisconsin River Ravines	5034	31	8326	263	32	4151	144
LfMN	Western Paleozoic Plateau	5681	7	15014	70	10	10184	60

[a]Previous periodic FIA inventories: Iowa, 1990; Illinois, 1985; Minnesota, 1977; and Wisconsin, 1983.
[b]Current annual FIA inventories conducted from 2002-2006.

Table 2. Proportion of the timberland by forest type group and stand size class in the subsections that compose the Driftless Area of the Midwest for previous and current US Forest Service Forest Inventory and Analysis (FIA) forest surveys.

Previous Inventories[a]			**Stand size class**[c]				**Stand size class**[c]		
Subsection by State	**% Timberland**	**% Oak-hickory**	% Large diameter	% Medium diameter	% Small diameter	**% Maple-basswood**[d]	% Large diameter	% Medium diameter	% Small diameter
LaWI	27.4	40.7	20.3	12.4	8.0	33.0	15.5	7.0	10.5
LbWI	37.5	61.1	34.3	20.6	6.2	10.2	4.2	2.2	3.8
LcIA	25.5	42.7	35.9	5.6	1.1	38.5	20.8	9.4	8.2
LcIL	15.6	64.4	55.9	8.6	0.0	9.0	9.0	0.0	0.0
LcMN	30.7	66.5	54.0	10.9	1.5	13.9	9.4	3.0	1.5
LcWI	36.8	64.4	48.0	10.1	6.4	18.9	8.5	5.1	5.3
LdWI	43.0	45.5	28.0	7.2	10.3	51.2	25.6	10.4	15.3
LeWI	8.9	70.0	58.5	4.9	6.7	27.2	11.2	4.6	11.4
LfIA	15.1	37.3	37.3	0.0	0.0	40.5	30.0	4.3	6.2
LfMN	7.1	54.8	45.3	7.9	1.6	35.2	31.2	4.0	0.0

Current Inventories[b]			**Stand size class**[c]				**Stand size class**[c]		
Subsection by State	**% Timberland**	**% Oak-hickory**	% Large diameter	% Medium diameter	% Small diameter	**% Maple-basswood**[d]	% Large diameter	% Medium diameter	% Small diameter
LaWI	29.7	46.4	25.1	13.8	7.5	26.5	13.7	9.1	3.7
LbWI	43.1	59.1	39.9	15.7	3.5	8.9	3.0	3.4	2.5
LcIA	30.4	47.8	39.8	5.4	2.5	39.5	30.7	7.4	1.4
LcIL	21.3	48.2	36.5	11.8	0.0	17.1	9.8	0.0	7.3
LcMN	31.5	53.4	42.1	11.0	0.2	22.7	11.4	8.1	3.2
LcWI	40.2	55.6	37.0	16.1	2.4	21.4	12.2	6.7	2.5
LdWI	41.4	46.9	30.5	14.5	1.9	37.2	25.1	9.5	2.6
LeWI	13.0	64.5	46.2	13.3	5.0	23.0	17.5	3.2	2.3
LfIA	20.4	41.1	28.6	6.4	6.1	47.7	29.2	8.5	10.1
LfMN	10.2	42.0	35.3	5.2	1.5	38.8	27.4	11.4	0.0

Table 2. Continued.

Previous Inventories[a]			**Stand size class**[c]				**Stand size class**[c]		
Subsection by State	% Timberland	**% Aspen-birch**	% Large diameter	% Medium diameter	% Small diameter	**% Elm-ash-cottonwood**	% Large diameter	% Medium diameter	% Small diameter
LaWI	27.4	11.9	1.9	7.1	2.9	7.0	4.1	0.0	3.0
LbWI	37.5	14.2	3.8	6.4	4.0	3.0	1.1	0.4	1.5
LcIA	25.5	1.8	0.0	0.0	1.8	9.2	9.2	0.0	0.0
LcIL	15.6	0.0	0.0	0.0	0.0	26.6	17.8	8.8	0.0
LcMN	30.7	7.3	1.9	3.9	1.5	12.3	9.1	2.0	1.3
LcWI	36.8	6.6	2.9	2.6	1.0	8.5	4.8	1.5	2.2
LdWI	43.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LeWI	8.9	2.7	0.0	2.7	0.0	0.0	0.0	0.0	0.0
LfIA	15.1	0.0	0.0	0.0	0.0	14.7	10.6	1.6	2.5
LfMN	7.1	5.4	2.9	2.5	0.0	4.6	3.0	1.6	0.0

Current Inventories[b]			**Stand size class**[c]				**Stand size class**[c]		
Subsection by State	% Timberland	**% Aspen-birch**	% Large diameter	% Medium diameter	% Small diameter	**% Elm-ash-cottonwood**	% Large diameter	% Medium diameter	% Small diameter
LaWI	29.7	7.8	1.8	4.6	1.4	8.4	3.5	2.1	2.9
LbWI	43.1	9.4	2.2	4.8	2.4	7.3	3.2	1.9	2.3
LcIA	30.4	0.0	0.0	0.0	0.0	6.2	5.3	0.8	0.0
LcIL	21.3	0.0	0.0	0.0	0.0	17.5	17.5	0.0	0.0
LcMN	31.5	1.9	0.0	1.8	0.2	15.4	8.1	4.9	2.4
LcWI	40.2	5.0	1.1	3.6	0.2	12.6	8.3	2.4	1.9
LdWI	41.4	4.4	1.0	3.2	0.2	4.9	2.8	0.9	1.2
LeWI	13.0	1.6	0.0	1.6	0.0	8.2	2.4	2.4	3.4
LfIA	20.4	0.0	0.0	0.0	0.0	8.9	4.6	3.0	1.4
LfMN	10.2	1.3	1.3	0.0	0.0	16.2	8.2	2.3	5.7

[a]Previous periodic FIA inventories: Iowa, 1990; Illinois, 1985; Minnesota, 1977; Wisconsin, 1983).

[b]Recent annual FIA inventories conducted from 2002-2006.

[c]Stand size classes: large = 11.0+ inches diameter at breast height (dbh) for hardwood trees (9.0+ inches dbh for softwoods); medium = 5.0-10.9 inches dbh for hardwood trees (5.0-8.9 inches dbh for softwoods); and small = < 4.9 inches dbh.

[d] Maple-basswood represents the forest type group maple-beech-birch, as designated by the US Forest Service (2007). Maple-basswood is most descriptive of the dominant tree species within this group in our study region.

Table 3. Change in the proportion of timberland, forest types, and stand size classes between the US Forest Service Forest Inventory and Analysis (FIA) previous and current inventories in the subsections of the Driftless Area of the Midwest. Previous periodic inventories were conducted: Iowa, 1990; Illinois, 1985; Minnesota, 1977; and Wisconsin, 1983. Recent annual FIA inventories were completed for each state from 2002-2006.

			Stand size class[a] (% Δ)				**Stand size class[a] (% Δ)**		
Subsection Code	% Δ Timberland	% Δ Oak-hickory	Large diameter	Medium diameter	Small diameter	% Δ Maple-basswood[b]	Large diameter	Medium diameter	Small diameter
LaWI	2.3	5.6	4.8	1.4	-0.6	-6.5	-1.8	2.2	-6.8
LbWI	5.6	-2.0	5.6	-4.9	-2.6	-1.4	-1.2	1.2	-1.3
LcIA	4.8	5.1	4.0	-0.2	1.4	0.9	9.8	-2.0	-6.8
LcIL	5.7	-16.2	-19.4	3.2	0.0	8.1	0.8	0.0	7.3
LcMN	0.8	-13.1	-11.9	0.1	-1.3	8.9	2.0	5.1	1.7
LcWI	3.4	-8.8	-10.9	6.1	-4.0	2.5	3.7	1.6	-2.8
LdWI	-1.6	1.4	2.5	7.3	-8.4	-14.0	-0.5	-0.9	-12.6
LeWI	4.2	-5.6	-12.3	8.4	-1.7	-4.2	6.3	-1.4	-9.1
LfIA	5.3	3.8	-8.7	6.4	6.1	7.2	-0.8	4.2	3.8
LfMN	3.0	-12.8	-10.0	-2.7	-0.1	3.5	-3.9	7.4	0.0

Table 3. Continued.

		Stand size class[a] (% Δ)				Stand size class[a] (% Δ)		
Subsection Code	% Δ Aspen-birch	Large diameter	Medium diameter	Small diameter	% Δ Elm-ash-cottonwood	Large diameter	Medium diameter	Small diameter
LaWI	-4.2	-0.2	-2.5	-1.5	1.4	-0.6	2.1	-0.1
LbWI	-4.8	-1.6	-1.6	-1.7	4.3	2.0	1.5	0.8
LcIA	-1.8	0.0	0.0	-1.8	-3.0	-3.8	0.8	0.0
LcIL	0.0	0.0	0.0	0.0	-9.1	-0.3	-8.8	0.0
LcMN	-5.4	-1.9	-2.1	-1.4	3.1	-1.0	2.9	1.2
LcWI	-1.6	-1.8	1.1	-0.8	4.1	3.4	1.0	-0.3
LdWI	4.4	1.0	3.2	0.2	4.9	2.8	0.9	1.2
LeWI	-1.1	0.0	-1.1	0.0	8.2	2.4	2.4	3.4
LfIA	0.0	0.0	0.0	0.0	-5.8	-6.0	1.3	-1.1
LfMN	-4.1	-1.6	-2.5	0.0	11.6	5.2	0.7	5.7

[a]Stand size classes: large = 11.0+ inches diameter at breast height (dbh) for hardwood trees (9.0+ inches dbh for softwoods); medium = 5.0-10.9 inches dbh for hardwood trees (5.0-8.9 inches dbh for softwoods); and small = < 4.9 inches dbh.

[b]Maple-basswood represents the forest type group maple-beech-birch, as designated by the U.S. Forest Service (2007). Maple-basswood is most descriptive of the dominant tree species within this group in our study region.

Table 4. Pearson and Kendall correlations with ordination axes from the non-metric multidimensional scaling (NMS) analysis. Variables represent the proportion of the forest type and proportion of forest type stand size classes that comprise the timberland in the subsection by state unit of analysis.

Forest type and stand size class[a] variables	**Axis 1** *r*	**Axis 2** *r*	**Axis 3** *r*
Oak-hickory	-0.01	-0.29	0.95
Oak-hickory (large diameter)	0.44	0.09	0.78
Oak-hickory (medium diameter)	-0.39	-0.82	0.41
Oak-hickory (small diameter)	-0.86	0.06	-0.14
Maple-basswood[b]	-0.21	0.82	-0.89
Maple-basswood (large diameter)	0.03	0.83	-0.77
Maple-basswood (medium diameter)	-0.36	0.44	-0.74
Maple-basswood (small diameter)	-0.41	0.27	-0.40
Aspen-birch	-0.60	-0.63	0.31
Elm-ash-cottonwood	0.87	-0.28	0.18
Elm-ash-cottonwood (large diameter)	0.91	-0.24	0.13
Elm-ash-cottonwood (medium diameter)	0.54	-0.15	0.37
Elm-ash-cottonwood (small diameter)	-0.07	-0.19	-0.16

[a]Stand size classes: large = 11.0+ inches diameter at breast height (dbh) for hardwood trees (9.0+ inches dbh for softwoods); medium = 5.0-10.9 inches dbh for hardwood trees (5.0-8.9 inches dbh for softwoods); and small = < 4.9 inches dbh.

[b] Maple-basswood represents the forest type group maple-beech-birch, as designated by the U.S. Forest Service (2007). Maple-basswood is most descriptive of the dominant tree species within this group in our study region.

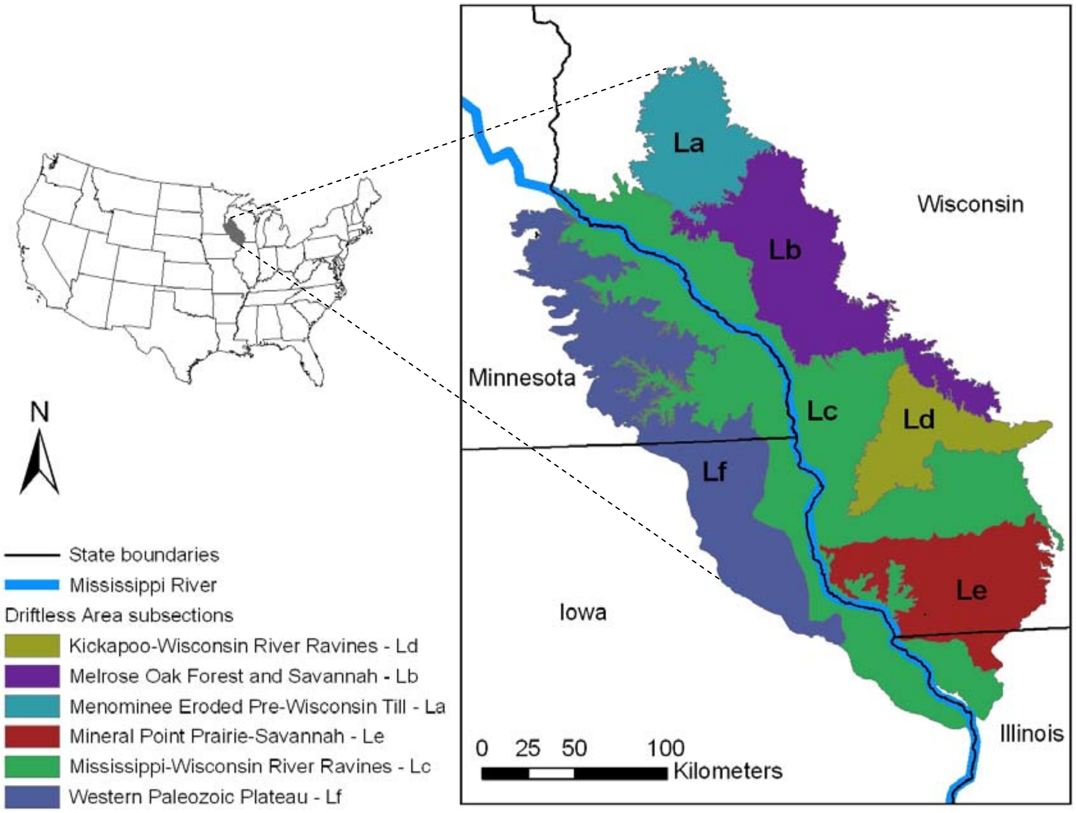

Fig. 1. Study area within North America and the subsection ecoregions that comprise the Driftless Area of the Midwest. The subsections (La-Menominee Eroded Pre-Wisconsin Till, Lb-Melrose Oak Forest and Savannah, Lc-Mississippi-Wisconsin River Ravines, Ld-Kickapoo-Wisconsin River Ravines, Le-Mineral Point Prairie-Savannah, and Lf-Western Paleozoic Plateau) fall within the Eastern Deciduous Forest province and North-Central U.S. Driftless and Escarpment section (US Forest Service 1994).

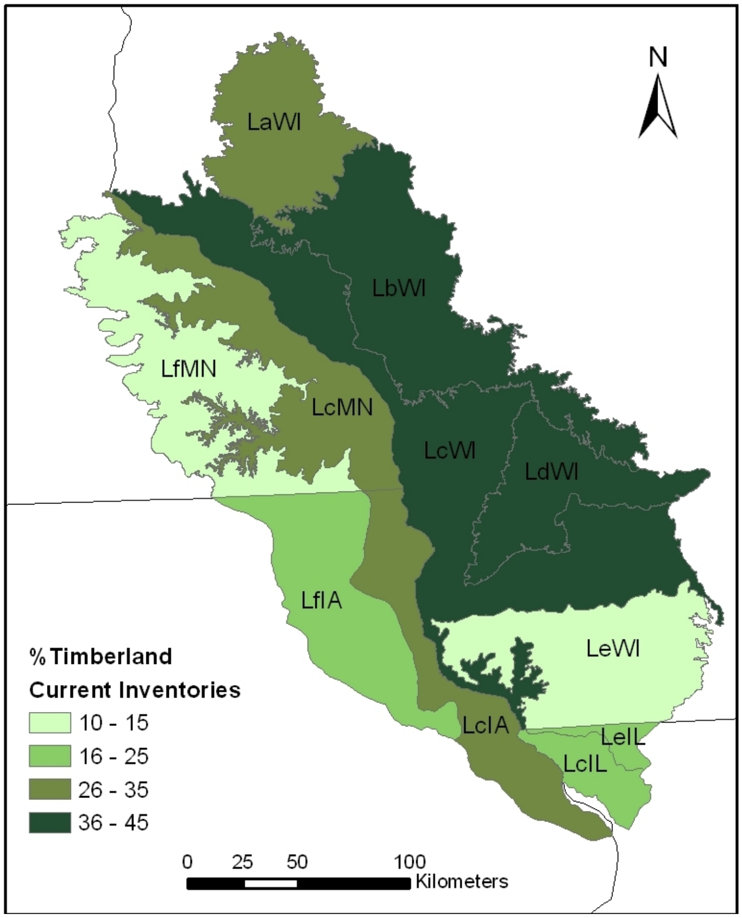

Fig. 2. Proportion of timberland by subsection ecoregions and state within the Driftless Area of the Midwest.

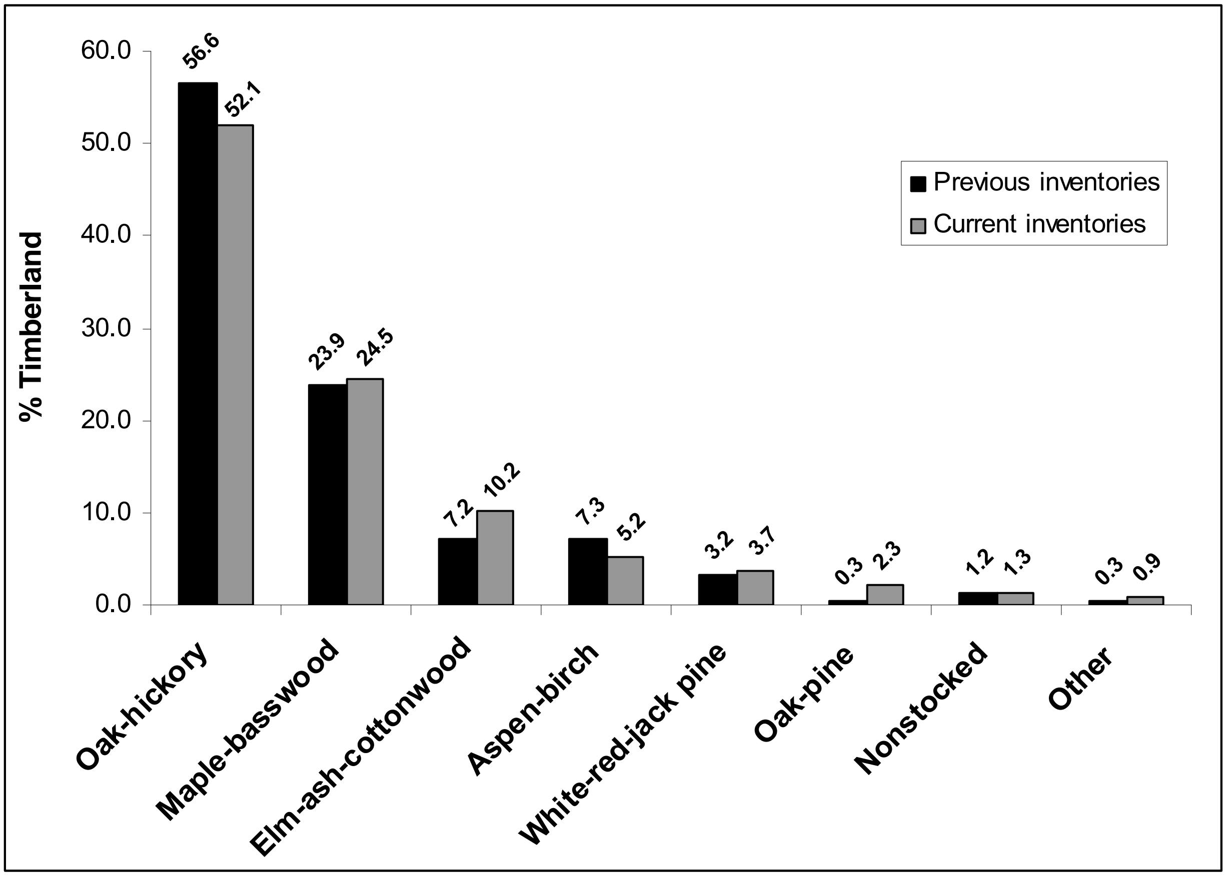

Fig. 3. The proportion of timberland by forest cover type in previous and current Forest Inventory and Analysis (FIA) inventories in the Driftless Area of the Midwest. “Other” includes forest type groups that comprised <1% of the timberland: pinyon-juniper (Eastern redcedar represents this group in this region), spruce-fir, and exotic softwoods (only found in the most recent inventory) groups. The maple-basswood forest type group is labeled as maple-beech-birch by the U.S. Forest Service (2007); however, maple-basswood is most descriptive of the dominant tree species within this group in our study region.

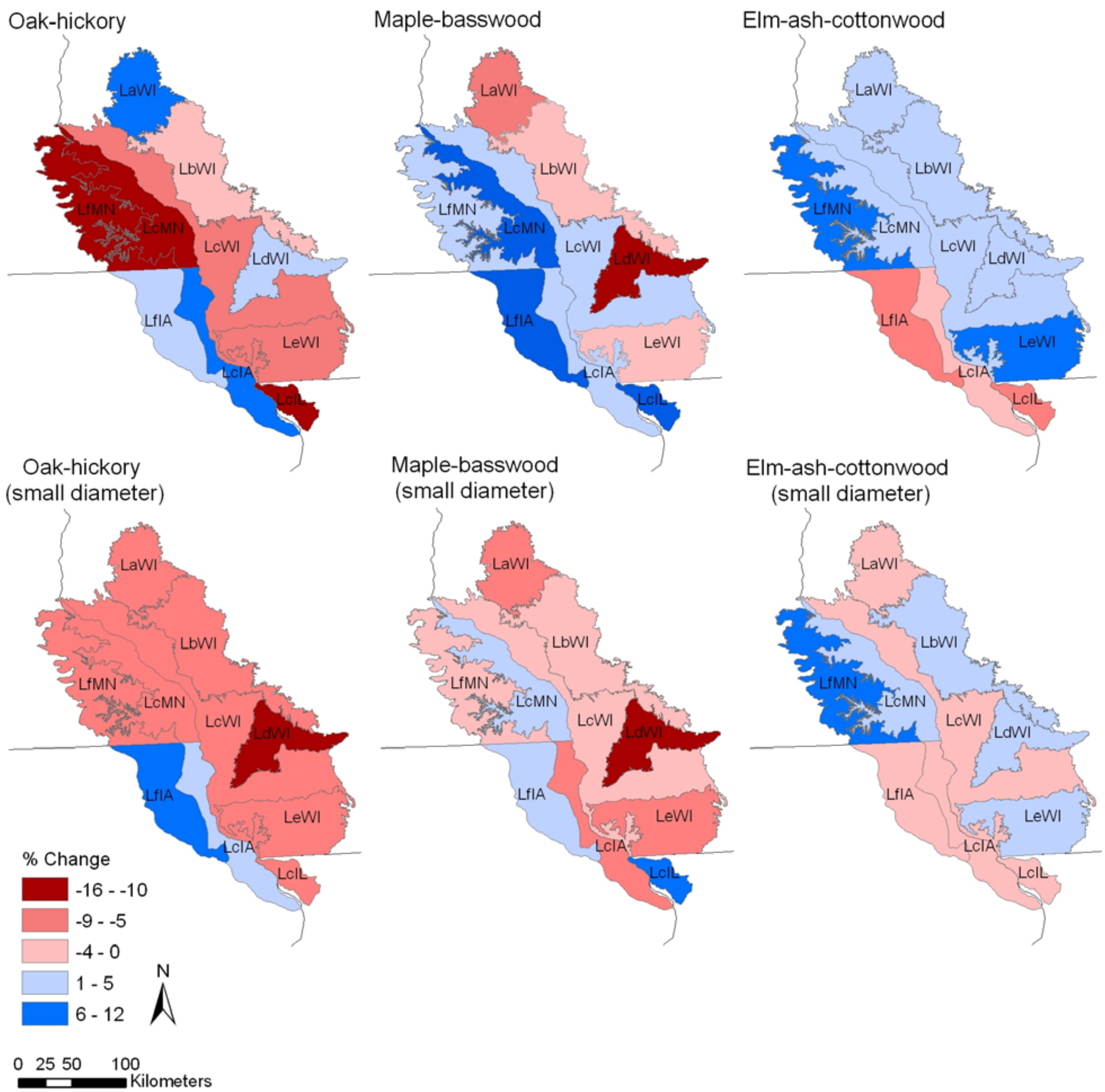

Fig. 4. Change within the last 20-30 years in the proportion of timberland in the three most dominant forest type groups and small diameter size class (< 5 inches diameter at breast height) in the Driftless Area of the Midwest.

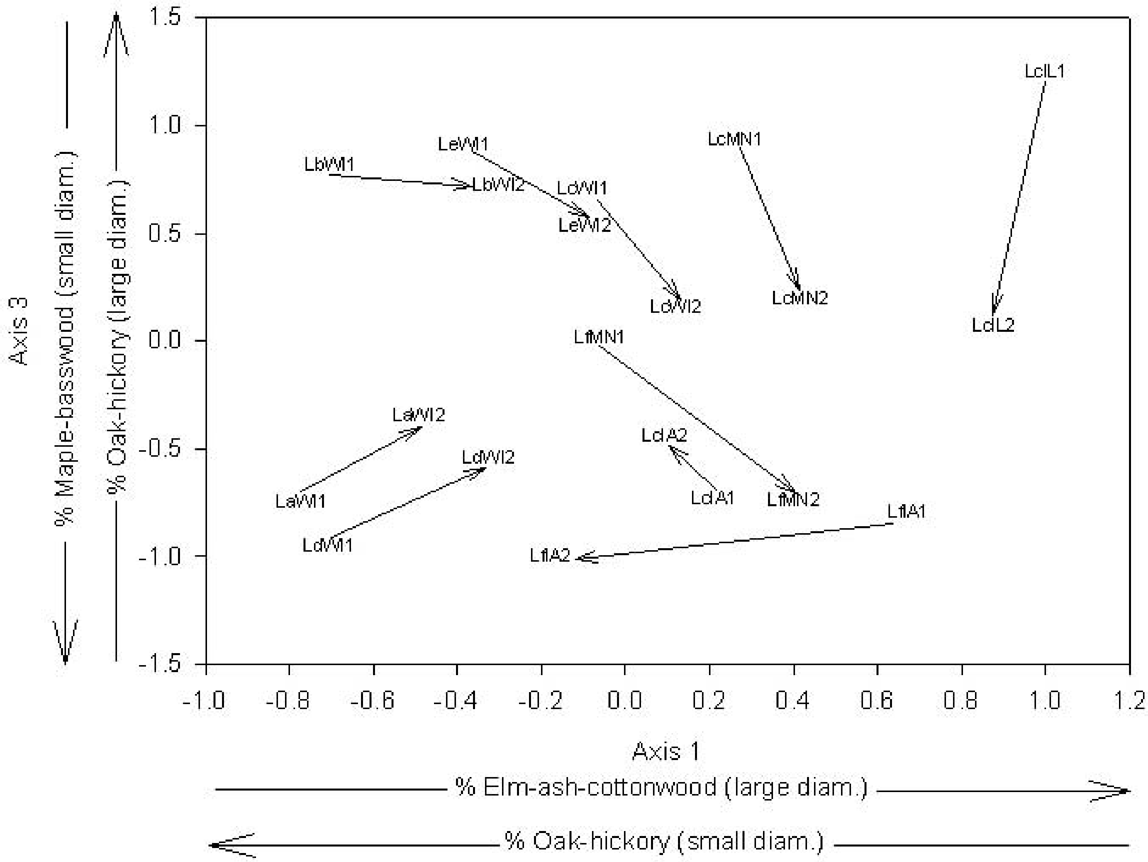

Fig. 5. Nonmetric multidimensional scaling (NMS) analysis showing the change within the 2-dimensional between the previous and current Forest Inventory and Analysis (FIA) surveys. Each vector connects periodic inventories to current inventories for one subsection by state.

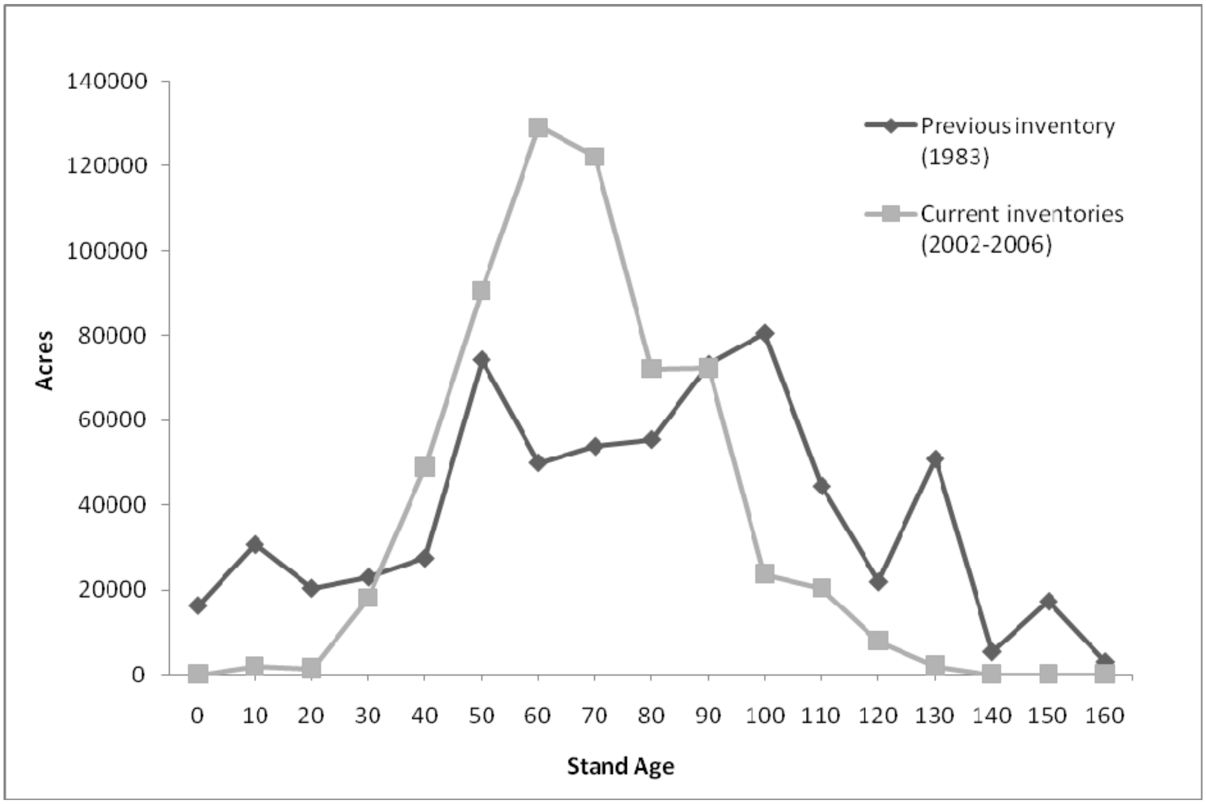

Fig. 6. Acreage of oak-hickory timberland, by ten-year age class, in the Wisconsin portion of the Mississippi-Wisconsin River Ravines (Lc) subsection of the Driftless Area of the Midwest. Stand age values represent the midpoint of the age class.

APPENDIX

Acres of timberland by forest type group (S.E.) by subsection and state within the Driftless Area of the Midwest, as estimated from USDA Forest Service Forest Inventory and Analysis (FIA) previous and current forest inventories.

Previous Inventories[a]	**Subsections of the Driftless Area**					
	Menominee Eroded Pre-Wisconsin Till		Melrose Oak Forest and Savannah		Mississippi-Wisconsin River Ravines	
Forest type groups	LaWI	LbWI	LcIA	LcIL	LcMN	LcWI
Oak-hickory	103297 (40.9)	392913 (7.8)	96903 (46.9)	28599 (181.1)	253802 (11.8)	648357 (6.0)
Maple-basswood[c]	83599 (39.7)	65794 (24.8)	87458 (50.2)	4000 (583.6)	53001 (26.6)	190391 (11.5)
Elm-ash-cottonwood	17799 (136.2)	19098 (53.2)	20810 (128.2)	11803 (305.6)	46900 (17.4)	85094 (28.6)
Aspen-birch	30200 (103.2)	91443 (18.4)	4104 (2248.1)	0	28000 (36.7)	65999 (25.7)
White-red-jack pine	15699 (88.8)	63743 (31.4)	0	0	0	13799 (58.6)
Oak-pine	0	0	5799 (518.8)	0	0	0
Eastern red cedar[d]	0	0	9302 (1574.7)	0	0	0
Spruce-fir	0	0	0	0	0	0
Nonstocked	2900 (3496.3)	10099 (113.4)	2700 (384.2)	0	0	2700 (438.3)
Total	253494	643091	227077	44401	381704	1006341

Current Inventories[b]	**Subsections of the Driftless Area**					
	Menominee Eroded Pre-Wisconsin Till		Melrose Oak Forest and Savannah		Mississippi-Wisconsin River Ravines	
Forest type groups	LaWI	LbWI	LcIA	LcIL	LcMN	LcWI
Oak-hickory	127503 (15.3)	437244 (7.4)	129050 (25.3)	29174 (183.3)	209219 (11.0)	611347 (6.6)
Maple-basswood[c]	72825 (19.0)	65638 (20.5)	106586 (21.7)	10342 (76.2)	89145 (19.1)	235649 (10.4)
Elm-ash-cottonwood	23144 (39.8)	53945 (20.5)	16640 (55.0)	10562 (76.0)	60192 (22.8)	138507 (15.0)
Aspen-birch	21328 (40.8)	69514 (19.0)	0	0	7561 (178.3)	54724 (48.1)
White-red-jack pine	19488 (41.4)	64542 (20.1)	0	0	10097 (90.6)	18107 (35.1)
Oak-pine	6354 (108.5)	35798 (37.5)	0	0	6611 (211.9)	17273 (90.1)
Eastern red cedar[d]	0	691 (380.8)	6625 (397.0)	9939 (73.0)	2479 (300.0)	3787 (176.2)
Spruce-fir	678 (121.7)	0	0	0	2043 (455.5)	2918 (224.4)
Exotic softwoods	0	0	0	0	0	2091 (381.0)
Nonstocked	3579 (67.9)	9879 (61.9)	7622 (60.2)	468 (906.9)	4502 (74.7)	13556 (35.8)
Total	274899	737251	266523	60485	391849	1097959

Previous Inventories[a]	Subsections of the Driftless Area				
	Kickapoo-Wisconsin River Ravines	Mineral Point Prairie-Savannah		Western Paleozoic Plateau	
Forest type groups	LdWI	LeIL	LeWI	LfIA	LfMN
Oak-hickory	156283 (14.5)	8600 (406.3)	77407 (32.4)	61319 (122.0)	54901 (25.3)
Maple-basswood[c]	175985 (15.2)	0	30106 (39.8)	66582 (61.4)	35301 (53.3)
Elm-ash-cottonwood	0	0	0	24207 (130.6)	4600 (127.9)
Aspen-birch	0	0	3000 (799.7)	0	5400 (120.2)
White-red-jack pine	0	0	0	6333 (27988.9)	0
Oak-pine	0	0	0	5800 (265.4)	0
Eastern redcedar[d]	0	0	0	0	0
Spruce-fir	0	0	0	0	0
Nonstocked	11299 (68.7)	0	0	0	0
Total	343566	8600	110513	164242	100202

Current Inventories[b]	Subsections of the Driftless Area				
	Kickapoo-Wisconsin River Ravines	Mineral Point Prairie-Savannah		Western Paleozoic Plateau	
Forest type groups	LdWI	LeIL	LeWI	LfIA	LfMN
Oak-hickory	155059 (13.1)	14896 (281.8)	104852 (15.3)	91440 (22.8)	59985 (57.4)
Maple-basswood[c]	123003 (24.4)	2380 (906.7)	37419 (39.7)	106018 (27.2)	55324 (23.1)
Elm-ash-cottonwood	16319 (61.1)	0	13276 (37.6)	19847 (48.3)	23143 (30.1)
Aspen-birch	14449 (39.7)	0	2661 (365.8)	0	1859 (612.3)
White-red-jack pine	10052 (52.4)	0	0	0	0
Oak-pine	8151 (139.7)	7751 (217.8)	2763 (380.9)	3568 (397.0)	0
Eastern redcedar[d]	0	0	0	0	2459 (299.9)
Spruce-fir	0	0	0	0	0
Exotic softwoods	0	0	0	0	0
Nonstocked	3562 (102.7)	1477 (106.8)	1626 (526.2)	1357 (535.1)	0
Total	330595	26504	162597	22230	142770

[a]Previous periodic FIA inventories: Iowa, 1990; Illinois, 1985; Minnesota, 1977; Wisconsin, 1983).

[b]Current annual FIA inventories conducted from 2002-2006.

[c] Maple-basswood represents the forest type group maple-beech-birch, as designated by the U.S. Forest Service (2007). Maple-basswood is most descriptive of the dominant tree species within this group in our study region.

[d]Eastern redcedar represents the pinyon-juniper forest type group as designated by the U.S. Forest Service (2007). Eastern redcedar (*Juniperus virginiana* L.) is the only species from the pinyon-juniper group that is recorded in our study region.

CHAPTER 6. THE POTENTIAL LOSS OF OAK: A LEGACY AND TREASURE OF THE DRIFTLESS AREA LANDSCAPE

Tricia G. Knoot, Lisa A. Schulte, and Brian Palik

Modified from a paper published in *BetterFORESTS* magazine

The Driftless Area and our oak heritage

The Driftless Area of the Midwest, encompassing a portion of southeastern Minnesota—also called the Blufflands Region of Minnesota, escaped the most recent glacial event and was once composed of a complex patchwork of prairies, savannas, and broad-leaved forests. Whereas agricultural fields and pastures have, for the most part, replaced the prairies and savannas, the deciduous forests, primarily oak-hickory forests, continue to blanket the steep slopes. As you walk through the mature oak forests in this region, your gaze will likely be drawn to the majestic canopy. However, to understand what the future might hold for oak, it is best to look towards the ground. You will most often find that the next generation of oak is largely absent in the understory; a concern that is often unnoticeable to those enjoying and recreating in these cherished forests.

Unique natural history

The oak-dominated forests have been a vital part of the Midwestern landscape for thousands of years, providing crucial habitat requirements for numerous wildlife and plant species. Also, humans have and continue to benefit from access to this oak resource for fuelwood and timber needs. The unique characteristics of oak species have allowed oak to thrive in the Driftless Area. For example,

- Oak species typically put more of their energy into a large taproot, as opposed to their shoots, and therefore are relatively drought tolerant.
- Their large acorns, which are an abundant and rich food source for many wildlife species such as turkeys, afford young seedlings substantial resources for early establishment.
- Oaks can also readily form stump sprouts if their main stems are damaged by fire or are harvested.

Whereas these characteristics of oak can increase their competitive advantage in certain environments, other conditions can limit their survival. Oaks are relatively shade intolerant and oak seedlings cannot usually survive for very long under the dense shade of mature forests, including parent oak trees. For example, under low light conditions, oaks shift resources to shoot growth in an attempt to capture more light. When this occurs, their ability to form a deep taproot is compromised, increasing vulnerability to drought and disturbance.

History of harvesting and disturbance

While the natural history of oak has contributed to its widespread dominance in the Driftless Area, these features of oak are also compatible with past forest management practices in the region. For example, Native Americans used fire in the prairie and savannas to enhance hunting opportunities and favor preferred plants. These fires likely swept into the adjoining deciduous forests, helping to perpetuate oaks. About two centuries ago Euro-Americans settled the region and heavily logged the forests, widely used forests for grazing, and contributed to the proliferation of forest fires throughout the region. Because oaks can readily stump sprout, the combined effects of fire, harvesting, and grazing promoted the dominance of oak. In addition, these disturbances opened up large areas that provided the much-needed light for oak seedlings, while also limiting competition from other species that were less fire and disturbance tolerant.

Current forest management and the competitive (dis)advantage of oak

Forest surveys in the region still show that mature oak forests dominate the landscape; however the next generation of oak forests is missing from the understory. As forest management practices have changed in the region, the characteristics of oak that once provided a competitive advantage currently contribute to its potential replacement by later-successional forest types, particularly by sugar maple-basswood forests. Presently, the prevailing harvesting practice in the Driftless Area is a single-tree selection approach. The removal of a few trees here and there does not typically provide enough light for oaks to become established and instead favors more shade-tolerant, later successional, tree species such as sugar maple. The widespread suppression of forest fires in the region also has allowed trees species that are less adapted to fire to flourish in the understory of mature oak forests.

Layers of threats to the future of oak

While single-tree harvesting practices help shift the competitive advantage to sugar maple-basswood forests in the region, a combination of factors further limits the successful establishment of oak. For example, invasive shrubs, such as common buckthorn (*Rhamnus cathartica* L.), compete with oak seedlings for light and nutrients. Also, the widespread browsing pressure by white-tailed deer, which often prefer oak seedlings and saplings to other tree species, inhibits oak survival. Other factors, such as oak-related diseases (e.g., oak wilt, oak decline) and pests (e.g., gypsy moth) also threaten the future of oak forests in the Driftless Area.

What does this mean?

The potential widespread loss of oak-dominated forests in the region may lead to a decline in critical habitat requirements for a variety of wildlife and plant species, which have adapted to the unique environmental conditions that oak forests provide. As an example, many animals depend on acorns, an abundant food source that is especially important to wildlife in the winter. The increase of shade-tolerant trees in the understory of mature oak forests can also contribute to the degradation of important ecological features of the landscape, including the cold-water trout streams that are highly prized in the region. For instance, as sugar maple seedlings and saplings blanket the understory of oak forests, fewer understory plants are able to survive in the densely shaded conditions, creating exposed soil conditions. As a result, the soil readily erodes off of the steep forested slopes into streams, creating layers of silt that could negatively impact the stream community.

What can we do?

As 90% of the forestland in the region is privately owned, the future of oak largely relies on the long-term vision and commitment of private landowners. While there are many factors that can inhibit oak regeneration, there are a variety of forest management techniques that can increase the likelihood that oaks establish successfully.

- **Fire:** Current research on oak forest regeneration suggests that the appropriate use of prescribed fire, prior to harvesting, can help to encourage oak seedling establishment. Once harvesting takes place, the use of periodic prescribed fires can continue to favor oak species by removing understory competitors such as non-desirable trees, vines, and invasive shrubs. Prescribed fire can be a valuable forest management tool; however, proper permits, training, and guidance are essential its for safe and effective use.

- **Harvesting:** Harvesting techniques, such as group selection, shelterwood, and variable retention, can provide sufficient light for oak establishment. While these techniques typically remove a large portion of the forest overstory at a site, some large, mature, trees can be retained, providing valuable wildlife habitat and a seed source for the future forest.
- **Direct seeding and planting:** If adequate oak regeneration is not available in the understory, direct seeding of acorns and planting of oak seedlings prior to harvesting can be used. However, protecting seedlings from deer browsing may be needed to realize success with these methods.
- **Professional guidance:** The variable and unique landscape in the region creates substantial differences in site conditions. Also, environmental factors, such as pest and disease outbreaks, can change over time. Therefore it is critical that private landowners and professional foresters work together to determine the most appropriate oak regeneration and management methods that are best suited to the site, current environmental conditions, and landowner goals. Because some oak management and regeneration methods can be costly, professional foresters can offer information and recommendations on suitable governmental cost-share programs. The Forest Stewardship Program through the Minnesota DNR is designed to offer free (see program requirements) technical assistance and guidance to private landowners and can be a useful way to begin long-term planning for oak. To find out more about the Minnesota DNR Forest Stewardship Program and how to contact your local DNR forester, see: http://www.dnr.state.mn.us/grants/forestmgmt/stewardship.html.

The future of oak will depend on partnerships

The task of restoring oak to the Driftless Area of the Midwest will likely be challenging. While focusing oak regeneration efforts on single forest stands is a step in the right direction, a combined effort that crosses property boundaries will help to further ensure widespread oak regeneration. For example, private landowners can join forces with their neighbors to more efficiently and economically eliminate invasive shrubs from the forest understory or coordinate harvesting events. By working together, we have a better chance of providing our children with an opportunity to enjoy the many benefits that oak forests have to offer.

CHAPTER 7.
GENERAL CONCLUSIONS

One natural resource professional, in discussing oak, identified the compelling question facing the retention of oak ecosystems in the Driftless Area of the midwestern U.S. and the need for timely action:

> "In my opinion, the oak resource . . . is . . . at a crossroads, where we can try and be more proactive about saying, 'This is an important resource and we're going to manage for it, and we're going to take care of it.'"

The fate of oak and oak-associated ecosystem goods and services is emblematic of the choice faced by ecologists, managers, and society related to all ecosystems that require periodic disturbance (Litvaitis 1993, Motzkin and Foster 2002). Unless actively managed for, oak-dominated forests will potentially be replaced by later successional forests (Chapter 5; Nowacki and Abrams 2008) and/or non-preferred forest types (Chapter 5), and future restoration efforts will need to rely on seeding and planting strategies that are often very expensive (Chapter 4). As a result, options for restoring these systems will be more limited in the future than at present (Chapter 4).

Our qualitative interviews with natural resource professionals provided depth understanding of the key ecological, economic, and social factors that are serving to inhibit oak regeneration. It was not surprising to find that private landowner decision making is central to the trajectory of forest change (Chapter 4), especially given that the forestland in the region is almost solely privately held. Ecological factors, such as deer herbivory, competition by understory herbs and woody species (including invasive shrubs), and the spread of oak pests and disease are directly inhibiting oak regeneration and also dissuade landowners from devoting resources towards oak regeneration (Chapter 2 and 4). In addition, we identified critical cross-scale interactions that offer the potential to influence oak system resilience. For example, climate change, market forces (i.e., stumpage prices for oak and maple), invasive species spread, societal demand for rural forestland, and forestland parcelization and exurban sprawl, operate at broader scales (from regional and global) but have cascading effects on landowner decision making at the forest stand level (Chapter 4).

Our analysis of system components, processes, feedbacks, and uncertainties identified several leverage points in the system, occurring at multiple scales, in which policy mechanisms could help persuade landowners to manage for oak (Chapter 2 and 4). For example, the economic and operational constraints associated with small forest parcels (a result of forestland parcelization) could be alleviated through cooperative management agreements between landowners (Kittredge 2005). In addition, funds devoted toward providing the infrastructure needed for more widespread prescribed burning on private lands, cost-share assistance for oak-specific management prescriptions, and increased landowner access to personal forest management guidance by a natural resource professional (thereby enhancing landowner knowledge of oak ecology and incentive programs available) could also contribute to improving oak regeneration on private lands (Chapter 2 and 4). However, state and federal natural resource budgets are limited and new funding for oak restoration is unlikely. Resources could be shifted away from support for other forest types (i.e., sugar maple) to oak management; however, such a shift would require clear valuation by society of the goods and services provided by oak forests above other forest types. This may be unlikely given that many natural resource professionals in our study welcomed forest conversion towards sugar maple (Chapter 4) and noted that most private landowners were willing to accept substitutes for oak because of economic and aesthetic trade-offs associated with the outcomes of oak management prescriptions (Chapter 2).

Our quantitative, spatially-explicit, assessment of forest change and oak-hickory timberland conditions corroborated the sentiments by regional natural resource professionals—oak-hickory timberland is declining throughout the region and sugar maple-basswood timberland appears to be replacing oak-hickory in some areas (Chapter 4 and 5). However, a non-preferred forest type, elm-ash-cottonwood, also appears to be increasing throughout the region (Chapter 5). Although many natural resource professionals viewed an increase in sugar maple as potentially beneficial (Chapter 4), climate change models suggest that future conditions in the region will be less suitable for sugar maple and more favorable for oak establishment (Prasad et al. 2007). However, if oak forests continue to decline, the natural regeneration of oak in the future would be less likely and the economic cost of restoration may be insurmountable. Thus, as noted by the natural resource professional above, “we” may be at a critical point in time to ensure that future generations have access to the ecosystem goods and services provided by oak forests.

LITERATURE CITED

Kittredge, D.B. 2005. The cooperation of private forest owners on scales larger than one individual property: international examples and potential application in the United States. *Forest Policy and Economics* 7:671-688.

Litvaitis, J.A. 1993. Response of early successional vertebrates to historic changes in land use. *Conservation Biology* 7:866-873.

Motzkin, G., and D. R. Foster. 2002. Grasslands, heathlands and shrublands in coastal New England: historical interpretations and approaches to conservation. *Journal of Biogeography* 29:1569-1590.

Nowacki, G.J., and M.D. Abrams. 2008. The demise of fire and “mesophication” of forests in the eastern United States. *Bioscience* 58:123-138.

Prasad, A. M., L. R. Iverson., S. Matthews., M. Peters. 2007. *A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States* [database]. Northern Research Station, USDA Forest Service, Delaware, OH. [Online] URL: http://www.nrs.fs.fed.us/atlas/tree.

ACKNOWLEDGEMENTS

I thank the Environmental Protection Agency (EPA), Science to Achieve Results (STAR) fellowship program, for funding my graduate studies and this research. The EPA has not officially endorsed this publication and the views expressed herein may not reflect the views of the EPA. Funding was also provided by the USDA Forest Service – North Central Research Station and Iowa State University. I sincerely thank the natural resource professionals for sharing their valuable time, experiences, and insights. I am truly humbled by the devotion, concern, and deep care expressed by the professionals towards the forest resources in the Driftless Area and decades of service that they have provided private landowners. Without their help and genuine interest in improving how private forests are managed, this research project would not have been possible.

I am especially indebted to my advisor, Dr. Lisa Schulte, for her invaluable guidance and unwavering enthusiasm, support, and patience. I am truly in awe of the high level of commitment that Lisa devotes to nurturing the talents of her graduate students while maintaining a highly successful research and teaching agenda, providing an exceptional example of a rigorous and realistic career in academia. I feel fortunate to work have worked with such an outstanding scientist, teacher, mentor, and sincere individual. In addition, I am immensely grateful for the guidance on project design, data interpretation, and editorial advice provided by my dissertation committee members, Nancy Grudens-Schuck, Mark Rickenbach, Brian Palik, James Miller, and Brent Danielson. This integrated project changed shape several times, and through the combined experience of my committee members, each alteration was an improvement. I am also very thankful for the countless hours of advice on interpreting qualitative data and insights into forest management, economics, and private landowner behavior offered by John Tyndall; his patience, support, and encouragement were instrumental to ensuring my success in pursuing a Ph.D.

Todd Hanson and Robin McNeely provided valuable GIS advice and were a pleasure to work with. I am also grateful for assistance by Mark Hatfield, who devoted innumerable hours of his time towards helping to calculate forest change and improving my understanding of the Forest Inventory and Analysis dataset. I thank Carrie Eberle, Bonnie Jan, Anna MacDonald, Krystina Smith, and Megan Boyd for providing help with transcribing interviews. I also thank the many faculty and staff members in the Department of Natural

Resource Ecology and Management, fellow graduate students, and the members of Dr. Schulte's lab who provided continuous advice and support; the value of their contribution to my development as a student is beyond measure. I am especially thankful for having the opportunity to closely share my academic experience with my fellow graduate student and office mate, Ryan Atwell. Ryan's wisdom, friendship, humor, energy, and joy for life are truly inspiring and improved my level of learning and enjoyment throughout.

I want to thank my friends and family for their continuous encouragement throughout my academic career. The unfaltering care and support provided by my husband, parents, in-laws, and my sister and her family allowed me to achieve a greater level of success than I thought possible. I especially wish to thank my husband—John, my daughter—Aysha, and my son—Kai, for their enduring love and critical dose of perspective in life.