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# Adaptation pathways: ecoregion and land ownership influences on climate adaptation decision-making in forest management

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**Abstract** Climate adaptation planning and implementation are likely to increase rapidly within the forest sector not only as climate continues to change but also as we intentionally learn from real-world examples. We sought to better understand how adaptation is being incorporated in land management decision-making across diverse land ownership types in the Midwest by evaluating project-level adaptation plans from a suite of forest management projects developed through the Climate Change Response Framework. We used quantitative content analysis to evaluate 44 adaptation-planning documents developed through the Framework's Adaptation Workbook within two ecoregional provinces of the Midwest. This approach was used to assess the components of adaptation planning, including the resources that adaptation actions targeted within planning documents, the climate changes and impacts of

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concern, and the adaptation strategies managers identified. Analyses of adaptation plans show that the most frequent climate changes and impacts of concern included alterations in the amount and timing of precipitation, increased vegetation moisture stress, and forest pest and pathogen impacts. Individual projects identified a diversity of adaptation options, rather than focusing singly on actions that aimed to resist climate impacts, enhance resilience, or transition systems. Multivariate analyses indicate that ecoregion and land ownership influenced adaptation planning, while the type of resources and the climate change impacts managers were concerned with were significantly correlated with the adaptation strategies selected during planning. This finding reinforces the idea that one-size-fits-all guidance on adaptation will be insufficient for land managers. Perceptions of relevant climate impacts differ based on regional and ownership contexts, which naturally leads to differences in preferred adaptation actions.

**Keywords** Climate change · Adaptation · Forest management · Natural resource planning

## 1 Introduction

Rapid environmental changes driven by climate change present new challenges for resource managers tasked with sustaining the long-term delivery of goods and services from managed ecosystems. Increasing temperature and variability in precipitation—combined with other novel anthropogenic stressors such as introduced pests and pathogens, invasive species, and altered fire regimes—increasingly necessitate flexible and adaptive management approaches that continue to meet land management objectives (Vose et al. 2012). This represents a departure from previous paradigms in forest management that either rely on historical conditions, assume an underlying natural equilibrium state (West et al. 2009), or apply top-down approaches to reduce natural variation and stabilize ecosystem dynamics (Holling and Meffe 1995). Managers are seeking ways to incorporate information on projected climate changes and associated impacts, as well as ecosystem vulnerabilities, into management actions that lead to success in meeting management objectives in forest landscapes.

### 1.1 Assessing advancement in adaptation

There have been increasing efforts to provide tools for assisting with adaptation—defined here as intentional actions that help human and natural systems accommodate climatic changes and subsequent impacts (Millar et al. 2007)—in natural resource management, such as frameworks for adaptation planning, decision support tools, and region-specific vulnerability assessments on projected changes in future climate (Keenan 2015). Despite these efforts, there is often limited guidance for implementing adaptation (Woodruff and Stultz 2016) often leading to the perception that existing plans lack connections to implementation strategies due to barriers in governance, professional networks (Moser and Ekstrom 2010), and human behavior (O'Brien and Wolf 2010). In a study within the Great Lakes region, many resource managers describe adaptation as focusing on the early-stage efforts—such as increasing awareness and building capacity—while implementation efforts were lacking (Petersen et al. 2013). Additionally, differences between the spatial scales that adaptation planning occurs and management decisions are made may impede implementation. For example, public land managers working for state agencies in the Upper Midwest felt most adaptation planning occurred at a regional scale and thus was not connected to actions occurring at the local level (Anhalt-Depies et al. 2016).

Case studies of adaptation are important for lowering the barriers to implementation necessary for more widespread application of adaptation practices (Bierbaum et al. 2013). Examples of adaptation efforts within forest management being put into practice exist (*See* Johnston and Edwards 2013) but are limited (Archie et al. 2012; Carlton et al. 2014). There is a growing recognition that the capacity to continue developing and implementing adaptation will be influenced by the degree to which managers have opportunities to learn from the practical experiences of others (Wise et al. 2014). Further, there are few examples of efforts to monitor and track progress in adaptation (Ford et al. 2013), and the need for monitoring will increase as more adaptation projects are implemented.

### 1.2 The Climate Change Response Framework

The Climate Change Response Framework (CCRF; www.ForestAdaptation.org) was initiated to provide a structured approach to developing adaptation decisions in natural resource management that accommodate diverse management goals, ecosystem types, and organizational structures (*See* Swanston et al. 2016 for an overview). An essential element of the CCRF is the use of in-person workshops where staff from the Northern Institute of Applied Climate Science facilitate hands-on training with land managers on adaptation planning, using real projects from their land base. Facilitators teach climate impacts based on regional vulnerability assessments developed for land managers (Brandt et al. 2016b) and guide managers through the Adaptation Workbook—a five-step adaptation-planning process (Janowiak et al. 2014)—to identify specific adaptation actions tailored to their project.

A key resource for the Adaptation Workbook-planning process is a menu of adaptation strategies and approaches derived from peer-reviewed literature and reports on adaptation (Swanston et al. 2016). This resource describes potential adaptation actions in a hierarchical structure, with ten broad strategies and 36 more-specific approaches that represent a continuum of adaptation options that range from resistance (preventing ecosystem change), resilience (enhancing capacity of the current ecosystem to recover to its original state after disturbance), and transition (intentionally anticipating and accommodating change to help ecosystems adapt to change and new conditions) (Millar et al. 2007; Swanston et al. 2016). As part of the Adaptation Workbook process, managers translate these broad conceptual strategies and approaches into prescriptive tactics that can be implemented within their existing management context (Janowiak et al. 2014; Brandt et al. 2016a).

Through the work of the CCRF, over 200 forest management adaptation projects have been developed throughout the Midwestern and Northeastern United States (Janowiak et al. 2014) (Fig. 1). These projects serve as examples of how land managers have integrated climate considerations into planning at scales that are consistent with where management decisions are made and actions are implemented (www.ForestAdaptation.org/demonstration-projects). Current project locations are predominantly in the Laurentian Mixed Forest (LMF) ecoregion of the Upper Midwest, representing approximately half of the projects, followed by the Midwestern and Eastern Broadleaf Forest ecoregions at 13% each. Five other ecoregions (Conifer-alpine Meadow, Central Interior Broadleaf Forest (CIBF), Northeastern Mixed Forest, Central Appalachian Broadleaf Forest, and Prairie Parklands) contain the remaining 23% of projects (Fig. S1). Land ownership varies across these projects, with 24 and 23% located on federal- and state-owned lands (respectively), followed by lands managed by private individuals (15%), tribal agencies and non-governmental organizations (11% each), municipalities (6%), county agencies (5%), universities, and lands managed cooperatively between multiple partners (3% each) (Fig. S2). Nearly 19% of

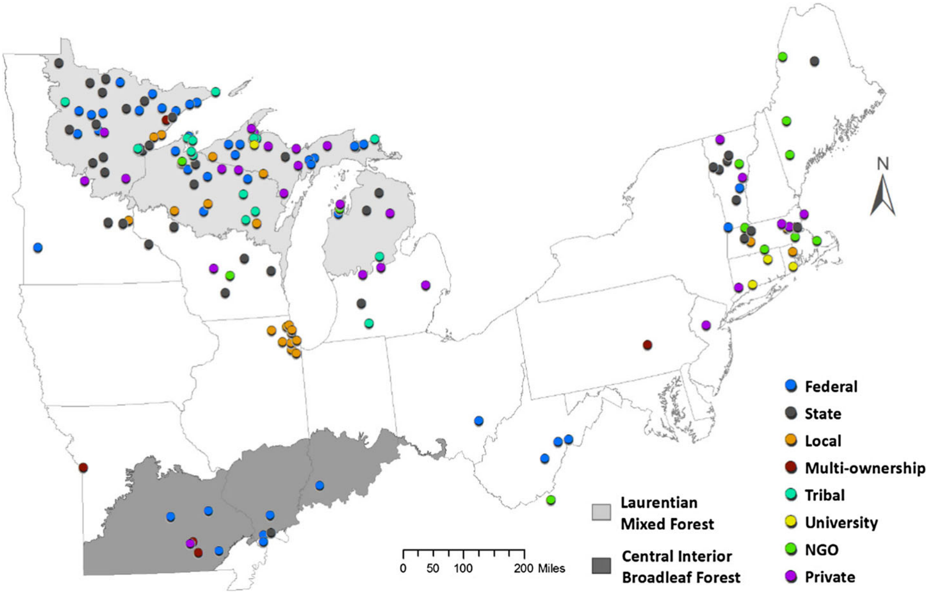



**Fig. 1** Distribution of over 200 adaptation projects throughout the Midwest and Northeast U.S. showing land ownership

these 200+ projects have implemented adaptation actions, while the majority (62%) have completed the planning process and will be implemented following completion of subsequent steps. Delays between planning and implementation, typically a year or more, are due to the normal logistics of final decision-making, translating plans into harvest prescriptions, setting up timber sales, and executing the contracts.

We sought to better understand the influences on how climate adaptation is being incorporated into forest management by evaluating completed adaptation-planning documents developed through the Adaptation Workbook. These projects represent diverse examples from public, private, and tribal lands in numerous forest types, and provide a view of organizations and locations where adaptation is being undertaken within forest management. We used the information provided by land managers as they completed the Adaptation Workbook to (1) describe the various components of adaptation to provide an overview of the resources, climate changes, and adaptation strategies managers are highlighting in adaptation planning; (2) determine how these components of adaptation planning were influenced by ownership type and location within two Midwestern ecoregional provinces: LMF and the CIBF; and (3) assess the linkages between the three components of adaptation planning to evaluate the needs of managers for region- and resource-specific adaptation information.

## 2 Methods

### 2.1 Content analysis

We evaluated adaptation-planning documents from the Adaptation Workbook using quantitative content analysis to examine components of adaptation plans. We selected projects for content analysis based on availability of adaptation-planning documents shared by project partners. Although some plans were available from projects throughout the eight ecoregional provinces (Cleland et al. 1997) covered by the CCRF, the majority of available adaptation plans were located in two ecoregions. We ensured adequate replication within an ecoregion to test for impacts of both ownership and ecoregion by selecting only projects from within LMF and CIBF ecoregions. Projects located within the LMF ($n$ = 37) selected for quantitative analyses represented all nine ownership types, whereas projects within the CIBF region ($n$ = 7) were all under federal ownership, and were included to compare to projects within the LMF region to examine regional influences on adaptation decisions.

We quantified contents of project-planning documents generated by using the Adaptation Workbook by categorizing: (1) resource concerns described within management objectives, (2) climate shifts and their impacts, and (3) adaptation strategies identified. Resources that were the focus within various management objectives in the project-planning documents describe the target of the adaptation actions, and were tallied within 20 categories for each project (Table S1). Similarly, climate impacts identified in the project-planning documents describe the site-specific impacts for the resources within management objectives that most concerned managers. These impacts were tallied within 20 categories for each project (Table S2). We characterized general choices of adaptation actions by quantifying the tactics listed within the project-planning documents according to the adaptation strategies and approaches to which they tiered (Butler et al. 2012). Furthermore, each adaptation strategy was categorized based on the aim of that management action—either to resist change, enhance resilience to change, or transition to anticipate change (Millar et al. 2007; Swanston et al. 2016)—in order to provide an overview of the adaptation options identified within each project. All adaptation projects within the CIBF region were all located on federally managed lands, allowing for comparison to federal projects in the LMF region while controlling for the influence of ownership. Additionally, the influence of ownership type was evaluated by comparing projects in federal- and private-owned lands within the LMF region.

## 2.2 Statistical analyses

We used non-metric multidimensional scaling (NMDS) to examine the abundance of resource concerns within management objectives, climate impacts, and adaptation strategies from adaptation-planning documents using the *vegan* package in R (Oksanen et al. 2016). Jaccard distance measures were used for all ordinations, which were required to have stress <20 (McCune and Grace 2002); dimensionality was optimized based on evaluation of the reduction in stress based on scree plots (Kruskal and Wish 1978). Impacts of ownership type and ecoregion on the components of adaptation decision-making (i.e., resource concerns, climate changes and impacts, and adaptation strategies), were evaluated using permutational multivariate analysis of variance using distance matrices (PERMANOVA) with the *adonis* function in *vegan* (Oksanen et al. 2016) with significance determined at $\alpha$ = 0.05. We used normalized abundance data for adaptation components from the previous analyses using Mantel tests in the *vegan* package in R to assess correlation between matrices of individual components. Dissimilarity of components was estimated using Jaccard distance measures. The standardized Mantel test statistic ($r$) was assessed using Monte Carlo randomization with significance determined at $\alpha$ = 0.05. Additionally, similarity in geolocation based on latitude/longitude for projects was tested for correlation with adaptation component variables using Euclidean distances to determine if projects located closer together had similar adaptation approaches.

## 3 Results

Ownership ($p = 0.005$) and ecological region ($p = 0.002$) affect overall adaptation components (Fig. S3). Analyses of the individual components of Adaptation Workbook plans provide additional insights into the factors influencing adaptation; namely, resource concerns described within management objectives were significantly influenced by region ($p = 0.005$), with greater emphasis on actions that target timber management objectives on federal lands in the LMF region (65%) compared to the CIBF region (30%), where projects had management objectives with a greater emphasis on wildlife, grasslands, wetlands, fisheries, and infrastructure (Fig. 2). Climate impacts identified by managers varied according to both region ($p = 0.01$) and ownership type ($p = 0.002$). Prominent differences in the climate changes of concern identified in plans highlighted greater concern in the CIBF region for changes in precipitation (Fig. 3). Specifically, concern was higher in the CIBF compared to LMF for more frequent extreme precipitation events (20.1 ± 7.8 and 7.0 ± 0.9%) and altered seasonality of precipitation (16.6 ± 3.3 and 8.9 ± 1.2%). Within the LMF region, ownership affected concerns over soil moisture stress, with lower concern within privately owned projects (3.7 ± 1.9%) compared to projects on federally owned lands (16.4 ± 3.5%).

Adaptation strategies selected within planning documents significantly differed between regions ($p = 0.03$, Fig. 4), whereas ownership type within the LMF did not significantly influence adaptation strategies ($p = 0.122$). Regional impacts largely highlighted differences in

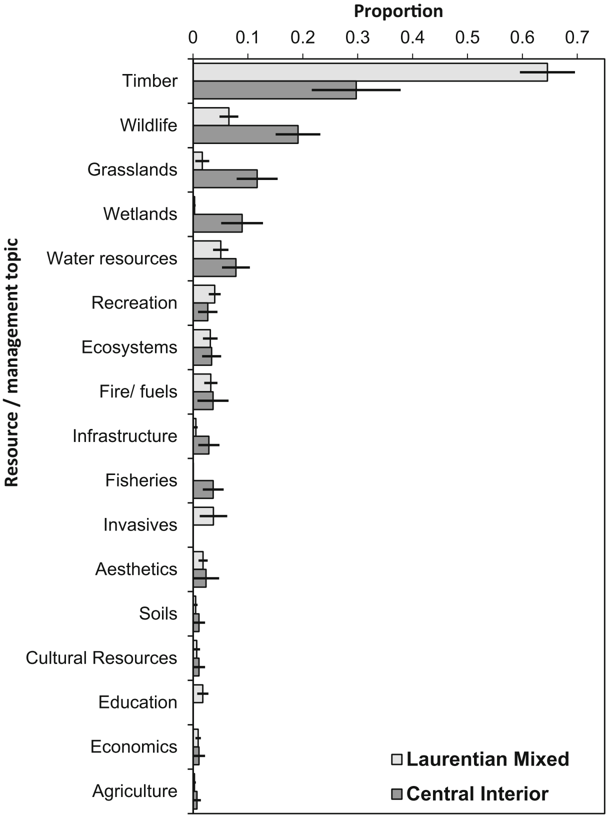
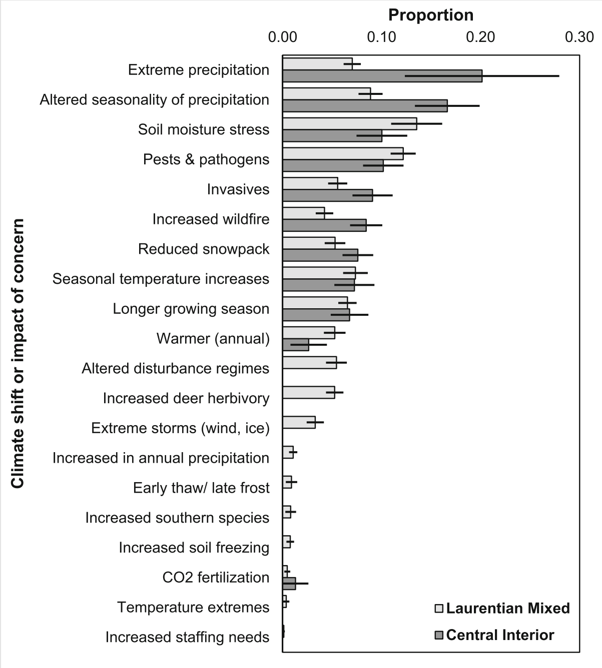


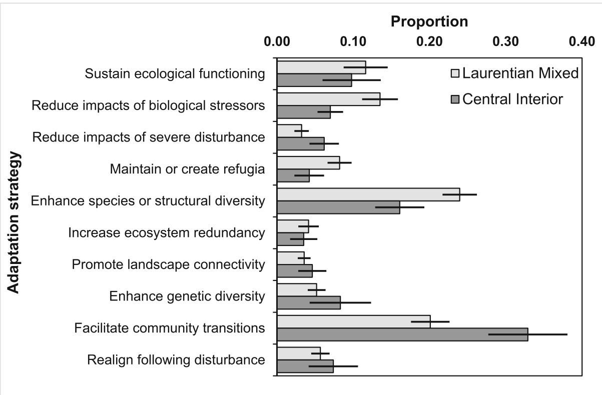

**Fig. 2** Relative frequency of resource concerns within adaptation-planning documents within two ecoregional provinces, the Laurentian Mixed Forest (*light gray*) and Central Interior Broadleaf Forest (*dark gray*). *Bar* indicates SE

**Fig. 3** Relative frequency of ite-specific climate changes and impacts identified as important within adaptation-planning documents within two ecoregional provinces, the Laurentian Mixed Forest (*light gray*) and Central Interior Broadleaf Forest (*dark gray*). *Bar* indicates SE




three of the most common strategies: greater emphasis in the LMF region compared to the CIBF region was placed on resisting changes by reducing the impacts of biological stressors (13.5 ± 2.3 and 7.0 ± 1.7%, respectively) and enhancing species and structural diversity (24.0 ± 2.2 and 16.1 ± 3.2%, respectively). Additionally, there was greater emphasis within the CIBF region compared to the LMF region on actions that facilitate community transitions (32.9 ± 5.2 and 20.1 ± 2.5%, respectively). Multiple adaptation strategies were selected within individual projects (6.3 ± 2.3), highlighting the diversity of adaptation actions managers identified to meet management goals rather than relying on a limited set of actions that may emphasize a narrow scope of adaptation aims (e.g., focusing only on actions that resist changes).

**Fig. 4** Relative frequency of adaptation strategies highlighted within adaptation-planning documents within two ecoregional provinces, the Laurentian Mixed Forest (*light gray*) and Central Interior Broadleaf Forest (*dark gray*). *Bar* indicates SE



Similarity of projects within adaptation components was correlated with similarity of other aspects of adaptation. The matrix of similarity in resource concerns was significantly correlated to both the matrices of climate changes and impacts ($r = 0.333$, $p = 0.007$) and adaptation strategies ($r = 0.437$, $p = 0.001$). The strongest correlation was found between similarity in climate changes and impacts and similarity in adaptation strategies ($r = 0.480$, $p = 0.002$). Tests of correlation between adaptation components and geolocation were all non-significant.

## 4 Discussion

Developing project-level management actions for climate adaptation is a relatively new challenge for land managers. Fostering an understanding of how managers are successfully addressing this challenge will aid in wider adoption into forest management planning and practices, as well as better meet the information needs of land managers and adaptation decision makers. In particular, there is a need to provide case studies of intentional adaptation efforts underway in natural resource management to support planning and implementation beyond early-stage actions (e.g., education, building capacity) (Petersen et al. 2013). We addressed this need by evaluating adaptation plans for existing projects with the U.S. Midwest region developed through the Climate Change Response Framework, which used a consistent approach for adaptation planning (Swanston et al. 2016). We identified the resource concerns towards which managers are directing adaptation actions, the most salient climate changes and ecosystem impacts for those resources, and the adaptation strategies being incorporated into on-the-ground management. Although this approach is informative for gaining insights into early efforts at climate adaptation in forest management, we recognize that the projects evaluated here do not represent a random sample of adaptation efforts with the region. Rather, the projects evaluated here signify the early adopters in climate adaptation within forest and natural resource management communities within the region, and may not be representative of broader adaptation efforts in the forest sector nationally.

### 4.1 Resource concerns for adaptation

Management goals identified during the adaptation-planning process were distributed among 20 different resource categories, highlighting the interdisciplinary nature of land management and the importance of managing for multiple objectives at a variety of scales. Timber management was the most frequently identified category (Fig. 2), which may signal a bias in the stakeholders engaging in adaptation planning, possibly due to the emphasis on vegetation management of the Adaptation Workbook and the associated menu of strategies and approaches. Other resources highlighted by managers include other non-forest ecosystem types, fisheries, water resources, recreation, and infrastructure. These results are consistent with the variety of resource concerns expected to be impacted by changes in climate, particularly on publically managed forest lands (Littell et al. 2012); Rodriguez-Franco and Haan 2015). Regional differences between LMF and CIBF ecoregions may reflect the landscape-scale heterogeneity of land cover, as well as differences in the anticipated vulnerability of resources to changes in climate. For example, managers within the CIBF region listed management goals for wetlands, water resources, and fisheries more frequently compared to managers within LMF region (Fig. 2), while also showing greater concern for climate impacts related to altered patterns of precipitation expected to impact these resources. In our analyses, land ownership did not significantly affect resource concerns of management goals, despite previous survey results indicating that private forest landowners cite lower concern for income from timber sales relative to objectives for wildlife, recreation, and esthetics (Bengston et al. 2009).

### 4.2 Climate shifts and impacts

Climate changes and their impacts frequently cited in adaptation planning largely focused on changes in amount and timing of precipitation (altered seasonality, extreme events), increased drought stress, and forest pest and pathogen impacts (Fig. 3). These results are consistent with results from previous studies, such as a survey of North American forestry professionals in the public and private sectors showing extreme weather events, water availability, and pest and disease damage as the climate impacts of greatest concern (FAO 2012). Similarly, managers ranked the impacts of invasive species, tree pests and disease, extreme precipitation, and drought highest in the Midwest region (Anhalt-Depies et al. 2016)) and eastern Canada (Morin et al. 2015). Moreover, manager concerns of climate effects on forest ecosystems in the Midwest reflect the impacts highlighted in broad regional assessments (Brandt et al. 2014; Butler et al. 2015; Handler et al. 2014a; Handler et al. 2014b; Janowiak et al. 2014, Swanston et al. 2011). Although uncertainty in forecasts for future precipitation is high, there is little doubt that moisture will become a more frequent stressor for forest ecosystems (Vose et al. 2012). Predicted decreases in late growing season moisture availability may be driven by interactions between increased summer temperatures and higher vapor pressure deficit (Luce et al. 2016). Additionally, increases in the frequency and intensity of extreme precipitation are occurring in the Midwest region concurrent with increased flooding events (Walsh et al. 2014). Interactions between climate change and impacts on forests and their pests and pathogens are poorly understood and challenging to predict (Ramsfield et al. 2016); however, it is clear that climate change is affecting the distribution of forest insects and pathogens with increased pest impacts anticipated (Weed et al. 2013).

### 4.3 Adaptation actions

The uncertainty and variability inherent in climate change mean that no single strategy will fit all situations, but instead require a toolbox approach where practices that can be selected in a flexible manner based on factors such as site conditions and the goals of management (Millar et al. 2007; Stein et al. 2014; Swanston et al. 2016; Janowiak et al. 2014). Some strategies may focus on near-term challenges while other actions address longer-term climate impacts. However, adaptation strategies that address impacts of climate changes that are not expected for decades may not be appropriate for projects with near-term management goals. For example, a survey of Midwest land managers suggests that adaptation actions were largely locally led efforts that focused on resisting current climate impacts in the near-term, while longer-term actions focusing on building resilience were initiated at higher organizational levels (Anhalt-Depies et al. 2016). Additionally, the survey results identified that no transformative actions were reported. In contrast, we found that managers identified numerous adaptation tactics that spanned the continuum from short- to long-term actions. Notably, the collection of adaptation practices across all projects showed the least emphasis on actions intended to resist change, whereas strategies to enhance resilience were the most common (Table 1). However, we were not able to assess the time frames associated with management goals to evaluate whether this influenced the selection of strategies and the emphasis

**Table 1** Percentage (SE) of approaches within categories of adaptation options with planning documents

| Category | All projects | LMF | CIBF |
|---|---|---|---|
| Resistance | 22.8 (1.7) | 23.8 (1.8) | 18.0 (3.5) |
| Resilience | 44.0 (1.2) | 45.1 (1.3) | 38.0 (2.7) |
| Transformation | 33.2 (2.1) | 31.1 (2.1) | 44.0 (5.8) |

*LMF* Laurentian Mixed Forest region, *CIBF* Central Interior Broadleaf Forest region

of the adaptation options they may represent. Anhalt-Depies et al. (2016) relied on a random selection of foresters and wildlife biologists across the region, whereas projects evaluated in this study were developed by managers participating in the CCRF. Differences in the use of actions to promote resilience and transition suggest that engagement with partnerships such as the CCRF may motivate managers to consider a greater range of adaptation options. Ultimately, identifying a diverse and multifaceted collection of adaptation actions can assist in addressing both short- and long-term challenges as well as meeting multiple management objectives (Steenberg et al. 2011). Our results highlight a diversity of adaption strategies within project-planning documents, suggesting that managers recognize the importance of this multifaceted approach.

Our evaluation shows that the most common adaptation strategies selected by managers across all projects were enhancing or restoring diversity of native species and age classes within forest communities (22.7 ± 2.0%) and facilitating plant community transitions by favoring or restoring native species that are expected to be better adapted to future conditions (22.1 ± 2.4%). Such strategies can provide climate mitigation benefits in addition to adaptation. Silvicultural practices that favor multiaged stands—such as irregular shelterwood systems—add complexity to forest structure and species composition and can simultaneously provide mitigation benefits by maintaining higher levels of carbon stocks (D'Amato et al. 2011). Similarly, strategies that select for or introduce future-adapted species will help systems maintain productivity and carbon stocks (Duveneck and Scheller 2016), particularly when used with tools such as spatially explicit maps with recommendations for adapted species importance (Iverson et al. 2016).

## 4.4 Influences on adaptation decision-making

Decision-making for climate adaptation does not occur in isolation, but is influenced by both social systems as well as organizations' internal processes (Smit and Wandel 2006). Our findings further support this and suggest that ownership as well as regional differences in social structures or ecosystem vulnerabilities play a significant part in determining the course of adaptation actions. The correlation between components of the Adaptation Workbook supports the use of a rational decision-making process (Moser and Ekstrom 2010), and suggests that the influences of region and ownership on the types of resource concerns can carry through into differences in relevant climate impacts identified and ultimately influence the selection of various adaptation strategies. These linkages between decisions made during the adaptation-planning process—and the influences regional and ownership contexts have on them—underscore the need for regionally appropriate and resource-specific information on climate change for land managers.

The regional differences in the emphasis on strategies that aim to facilitate system transitions were an unexpected outcome. Similar to the need to define the intent of "resilience" actions in adaptation (Fisichelli et al. 2016), our evaluations suggest that managers' perceptions of the directionality of ecosystem changes within approaches that emphasize system transition may ultimately assist understanding in science-management partnerships. Content analysis revealed key differences in this directionality of community transition between the LMF and CIBF regions that emphasize both the change in system characteristics from historic conditions to the present, as well as desired conditions into the future. In the LMF, managers recognized the changes in forest community structure from historic conditions dominated by uneven-aged stands to present-day conditions consisting of more even-aged stands resulting from afforestation following previous harvests, while species composition at broad spatial scales has increased due to increased prevalence of early successional communities. In this region, managers largely emphasized adaptation actions that alter species composition through an increase future-adapted species by favoring or planting more heat- and drought-tolerant species, typically by expanding species ranges northward (Fig. 5a). Some variation was noted in manager preference for changes to structural diversity dependent on forest type, with increases

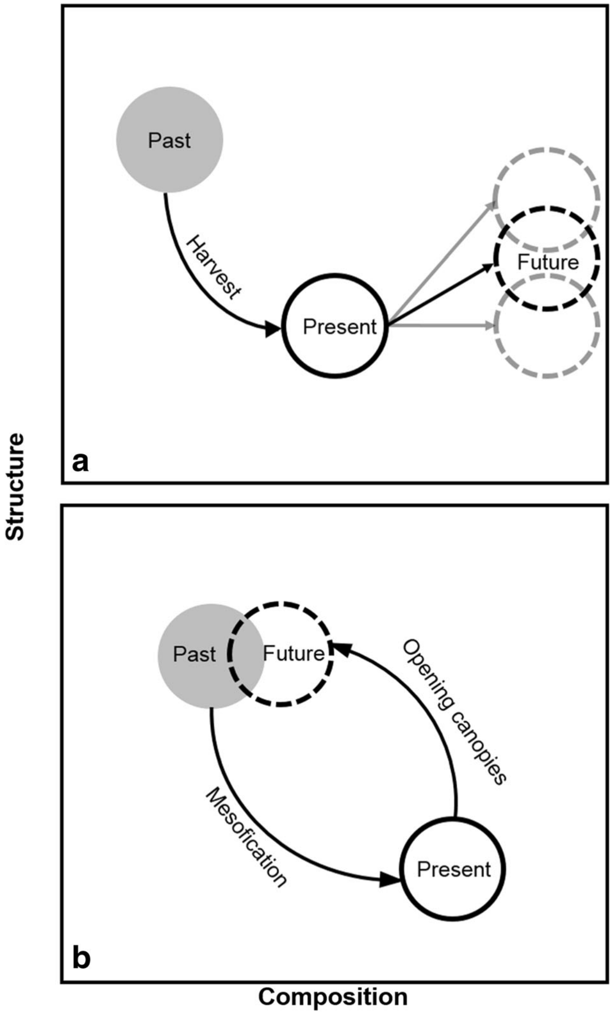



**Fig. 5** Conceptual model of observed changes from past (*gray circle*) to present (*solid circle*) in forest structure and species composition, as well as desired future conditions (*dotted circle*) resulting from strategies that facilitate community transitions with the Laurentian Mixed Forest (**a**) and Central Interior Broadleaf Forest (**b**) ecoregions

in uneven-aged conditions for some forest types and even-aged conditions in early successional forest types. In contrast, managers in the CIBF region identified that changes from historic conditions to the present often consisted of a loss of open canopy conditions and the subsequent alterations in species composition to more shade-tolerant, mesophytic species. Within this region, managers emphasizing community transition largely sought to restore historic conditions by opening canopy gaps and restoring the populations of oak and pine species once prevalent within the region's forests (Fig. 5b). These historically prevalent species are anticipated to do well as temperatures increase and drought stress becomes more frequent.

## 5 Conclusions

Climate change poses significant challenges to those tasked with managing ecosystems, yet significant progress has been made incorporating adaptation actions into management decision-making across different regions and ownerships within the Midwest and Northeastern US. The influence of the regional (biophysical and/or social) and organization (ownership type) context within which projects are developed can have substantial influence on climate adaptation decisions, including the resources to which adaptation actions are directed, the climate impacts of concern, and the aims of the adaptation actions the managers select for implementation. These results highlight the diversity of management strategies identified within adaptation planning, providing a range of adaptation options for managers that address both current and anticipated climate impacts, as well as short- and long-term management goals and objectives. The adaptation recommendations and decisions within planning documents illustrate various adaptation pathways influenced by the regional and organizational contexts within which they were developed, and serve as valuable examples for future land managers.

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