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A menu of climate change adaptation actions for terrestrial wildlife management

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Abstract

The real-world application of climate change adaptation practices in terrestrial wildlife conservation has been slowed by a lack of practical guidance for wildlife managers. Although there is a rapidly growing body of literature on the topic of climate change adaptation and wildlife management, the literature is weighted towards a narrow range of adaptation actions and administrative or policy recommendations that are typically beyond the decision space and influence of wildlife professionals. We developed a menu of tiered adaptation actions for terrestrial wildlife management to translate broad concepts into actionable approaches to help managers respond to climate change risks and meet desired management goals. The menu includes actions related to managing wildlife populations as well as managing wildlife habitat. We designed this resource to be used with the Adaptation Workbook, a structured decision-support tool for climate adaptation. We describe real-world examples in which managers have used the Wildlife Adaptation Menu to integrate climate adaptation considerations into wildlife management and conservation projects. Our examples illustrate how a comprehensive and structured menu of adaptation approaches can help managers brainstorm specific actions and more easily and clearly communicate the intent of their climate adaptation efforts.

KEYWORDS
adaptation, climate change, management guidance, planning, terrestrial, wildlife

Climate change is a significant threat for wildlife around the world (IPBES 2019, Jarzyna et al. 2019). The magnitude of projected change by the end of the century will present serious and multifaceted challenges for biodiversity, particularly for species that specialize on vulnerable habitats or a narrow range of conditions (Thomas et al. 2004). The rapid on-going and projected changes in climate will likely exceed the adaptive capacity of many wildlife species (Harrisson et al. 2014, Lenoir and Svenning 2015, Nicotra et al. 2015). The ecological impacts of modern climate change will be widespread but not uniform, as individual organisms and populations vary in exposure, sensitivity, and adaptive capacity (Foden et al. 2019, Weiskopf et al. 2020). Even species that are not directly threatened by changes in seasonality, phenology, or extreme events may be affected as climate change indirectly affects habitat quality, exacerbates existing stressors, and leads to novel interactions (Staudt et al. 2013).

Given the severity and pervasiveness of climate change impacts on wildlife, conventional paradigms of wildlife management may no longer be adequate to achieve conservation goals (Abrahms et al. 2017). For example, habitat restoration and habitat protection might not ensure the long-term persistence of a species if the climate across the species' range shifts beyond physiological thresholds (Kostyack et al. 2011). In this context, adaptation refers to the intentional, planned adjustments to natural and human systems to reduce the risks from climate change (Stein et al. 2014, Swanston et al. 2016). Climate change vulnerability is conventionally expressed as a combination of the exposure, sensitivity, and adaptive capacity of a system or organism, and therefore climate change adaptation decisions often stem from the desire to minimize potential impacts or enhance adaptive capacity (Glick et al. 2011).

A persistent obstacle to implementing climate adaptation has been that guidance for wildlife management and conservation tends to be generic or mismatched to the actual decision space and authority of most wildlife managers. Literature on climate adaptation strategies focuses on establishing and evaluating protected areas, improving connectivity, and enacting laws and policies (Heller and Zavaleta 2009, Mawdsley et al. 2009, Oliver et al. 2012, Stein et al. 2013, Prober et al. 2019). A recent review of wildlife management publications underscored the emphasis on protected areas and other broad-scale recommendations in contrast to the limited studies on adaptation to address reproduction, survival, and human-wildlife conflicts (LeDee et al. 2021). This is not to diminish the importance of broad-scale initiatives as a necessary tool for helping wildlife cope with climate change, but there appears to be a disconnect in the current management paradigm when applied to the rapidly evolving and complex challenges of climate change. Additionally, the most familiar wildlife management practices have likely been designed with the intent of restoring or retaining historical conditions, an approach that may be less applicable in an era of relentless climate change (Collof et al. 2017, van Kerkhoff et al. 2019).

Wildlife managers are faced with the quickly expanding array of publications, recommendations, and tools related to climate change risk assessment and adaptation planning. Adaptation planning frameworks may guide practitioners to develop conceptual models to identify potential intervention points for climate adaptation (Cross et al. 2012), brainstorm options to reduce potential risks from climate change (Stein et al. 2014), or use quantitative models to optimize outcomes between conflicting management actions (Convertino and Valverde 2013). Thurman et al. (2020) propose evaluating optimal adaptation pathways (persist in place or shift in space) for particular species based on an assessment of the attributes of their natural adaptive capacity. The Resist-Accept-Direct framework also aims to help managers identify a general pathway based on ecological, societal, and financial feasibility (Lynch et al. 2021).

Guidance about identifying specific adaptation practices for implementation is lacking, however. More than a decade ago, Heller and Zavaleta (2009:29) emphasized the need to organize the "sea of adaptation ideas" into a structure to guide adaptation planning. A recent survey of state wildlife management agencies revealed that managers continue to express the need for best management practices related to climate adaptation and examples of successful adaptation (Johnson 2021). In response to this call and others like it, we created the Wildlife Adaptation Menu, a consolidated and organized collection of adaptation actions for terrestrial wildlife management, to support the work of natural resources professionals by providing the best available climate adaptation science in a user-friendly format. A critical aspect of its development was demonstrating its viability and application through real-world management projects (Janowiak et al. 2014) that include a variety of species, habitat types, and management goals. The Wildlife Adaptation Menu, similar to previously published adaptation menus for other natural resource topics, (O'Toole et al. 2019, Shannon et al. 2019, Tribal Adaptation Menu Team 2019, Ontl et al. 2020, Janowiak et al. 2021), contains a comprehensive list of adaptation actions that may be selected based on the goals of managers and landowners, as well as the specific context of the place and system. The adaptation concepts in the Wildlife Adaptation Menu are presented hierarchically to help users connect broad concepts to more precise tactics for implementation. Here, we present an overview of how we developed the menu and real-world demonstrations that illustrate how it can be used to support climate change adaptation by providing wildlife managers with actionable and organized ideas.

MENU DEVELOPMENT

We conducted a broad literature review of terrestrial wildlife management and conservation publications to gather both general and specific management recommendations related to climate change adaptation (LeDee et al. 2021). This search yielded over 2,300 distinct adaptation recommendations, which included detailed suggestions for specific species (e.g., managing opossum [*Didelphis virginiana*] predation and maintaining high adult cockatoo [Cacatuidae] survival) as well as many general pronouncements that could be applied at many scales and in many contexts (e.g., taking measures to prevent or control invasive species can enhance an ecosystem's resilience to climate change).

We subsequently collated the master list of adaptation recommendations into a tiered list of general strategies and more specific approaches (Figure 1). Following the definitions established by Swanston et al. (2016), strategies are broad adaptation responses that consider ecological conditions and overarching management goals. Strategies identify general adaptation intent but are written specifically enough to capture recognizable ideas within a professional discipline such as forestry or outdoor recreation. Approaches are more detailed adaptation responses that articulate different ways that a general strategy could be employed. Strategies are intentionally generic enough to contain several approaches, but strategies also need to be specific enough that the user can clearly anticipate the kinds of ideas that are included within. We also illustrated each approach by including several tactics that provide distinct examples of how an adaptation approach could be implemented in a real-world management context. We drew tactics from published literature and case studies where possible.

We deliberately classified ideas related to wildlife population management and wildlife habitat management into 2 distinct sections of the menu, which helped consolidate thousands of climate adaptation recommendations into a more manageable and useable list. Likewise, wildlife managers often have a clear focus on one of these topics in their professional responsibilities, and we wanted users of the menu to be able to quickly identify adaptation strategies and approaches that are within their realm of influence.

After the development of an initial menu based on the literature review, we hosted 3 in-person, 2-day workshops to iteratively test and refine the Wildlife Adaptation Menu with our target audience of wildlife management professionals (September 2018 in Bath, MI; April 2019 in Madison, WI; and June 2019 in Lincoln, NE). A total of 84 wildlife professionals participated in these workshops. Workshop participants included representatives from federal, state, and tribal natural resource management agencies, as well as local and national conservation NGOs with a focus on wildlife management. We structured the workshops to facilitate small groups to use the Adaptation Workbook planning process (Figure 2; Swanston et al. 2016, Schmitt et al. 2021) and the Wildlife Adaptation Menu to develop plans for real-world wildlife management projects. Participants brought their own projects to the workshop, each with specific management objectives. The workshops facilitated a total of 27 such projects, which spanned a wide diversity of focal wildlife taxa, habitat types, ownership contexts, and geographic scales. We presented summaries of 2 adaptation demonstration projects below.

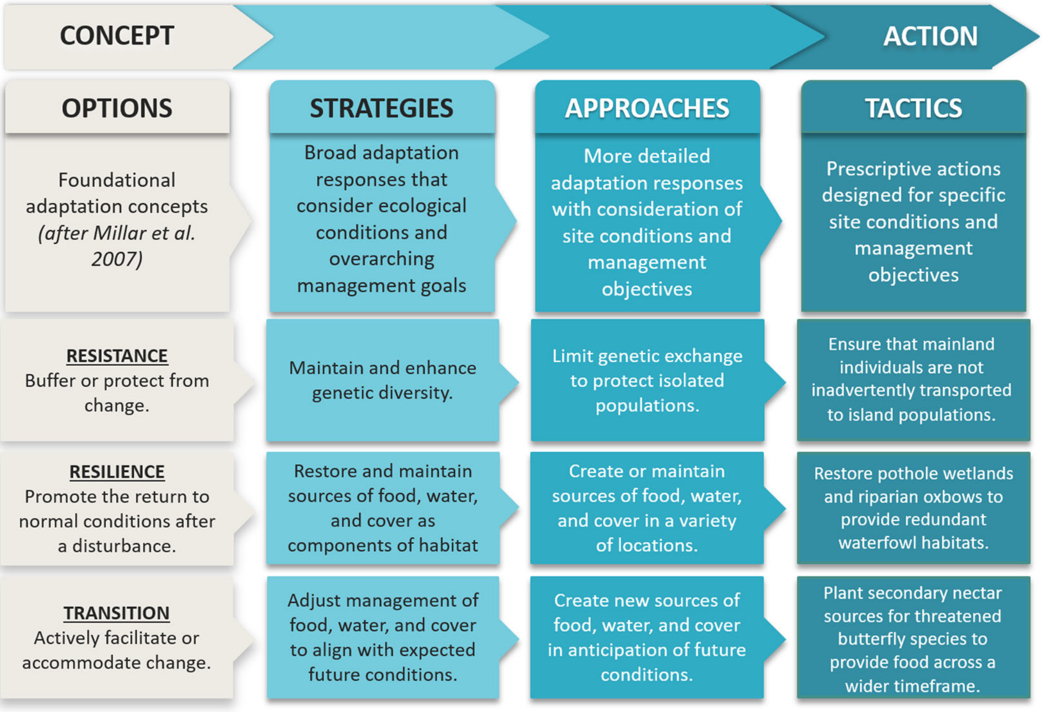

FIGURE 1 Adaptation options, strategies, approaches, and tactics represent a continuum of increasing specificity from general pathways to specific actions for implementation. Adaptation strategies and approaches represent intermediate tiers in this hierarchy that help managers navigate the multiple ideas in the Wildlife Adaptation Menu. Modified from Swanston et al. (2016). Examples are provided to illustrate strategies, approaches, and tactics for each of 3 general adaptation options (resistance, resilience, and transition, following Millar et al. (2007).

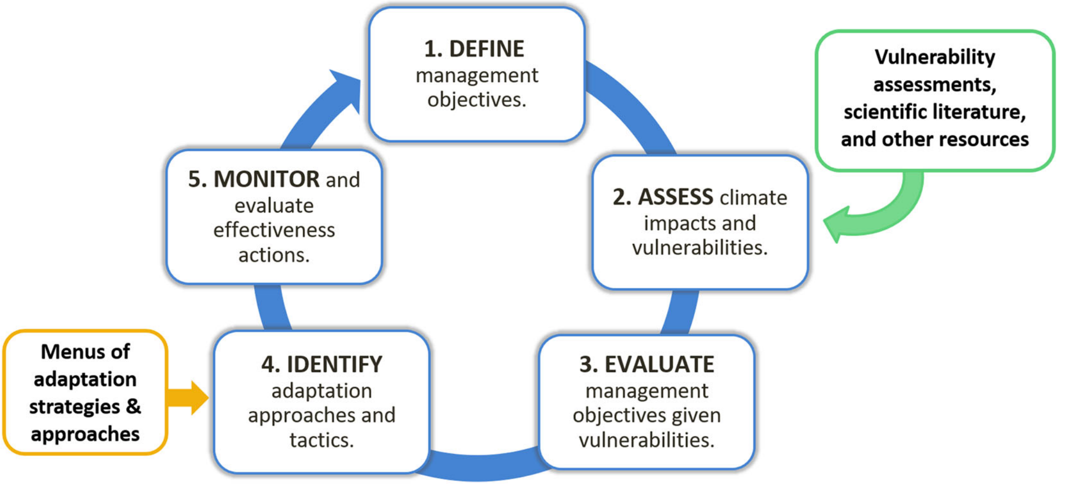

FIGURE 2 The Adaptation Workbook is a structured process to support climate adaptation planning for natural resources management (Swanston et al. 2016). Menus of adaptation strategies and approaches are used to support creative thinking and to define the intention behind selected adaptation tactics.

We devoted roughly half of the in-person workshop time to allowing small groups to proceed through the Adaptation Workbook steps for their respective projects and used the remaining time for large-group discussion and feedback (Example Workshop Agenda, available in Supporting Information). Participants were prepared before the workshop through individual conversations about project selection, as well as webinar presentations on regional climate change projections and climate change adaptation concepts and principles.

These test workshops allowed us to gather direct feedback from our target users, and each workshop concluded with an open discussion as well as individual questionnaires about how the menu could be improved (Feedback Questionnaire, available in Supporting Information). We revised the menu following each workshop based on this input. Participant feedback helped us improve clarity and limit redundancy across the menu, identify specific tactics to illustrate adaptation approaches, and fill notable gaps in our coverage of the topic.

WILDLIFE ADAPTATION MENU

After multiple phases of consolidation, reorganization, and refinement, the final Wildlife Adaptation Menu contains 13 broad strategies and 80 associated approaches (Table 1). The full narrative of the menu includes a concise description of each strategy and approach as well as hundreds of example tactics (Wildlife Adaptation Menu – Complete Narrative with Example Tactics, available in Supporting Information). Strategies 1–7 focus on wildlife population management, whereas strategies 8–11 focus on habitat management. Strategy 12 contains approaches related to intentionally taking no action, and strategy 13 more explicitly involves human communities in wildlife management.

MENU APPLICATION

The Wildlife Adaptation Menu is designed to be used in conjunction with the Adaptation Workbook (Swanston et al. 2016, Figure 2), but it may also be used with other structured climate adaptation planning processes such as the Adaptation for Conservation Targets Framework (Cross et al. 2012), Resist-Accept-Direct (Lynch et al. 2021), or Climate-Smart Conservation (Stein et al. 2014). Using the menu within a decision-support framework helps managers carefully articulate their conservation objectives, consider locally relevant climate change vulnerabilities, re-evaluate the feasibility of their objectives, and select and refine ideas for implementation. The Wildlife Adaptation Menu is not a checklist of recommended best practices or guidelines to follow in all situations. Rather, it is a collection of possible actions that the users select according to their professional judgement. The menu intentionally spans a broad range of management approaches, and thus contains some adaptation actions that are conflicting or mutually exclusive.

Hundreds of climate adaptation demonstration projects have been developed with the Adaptation Workbook process, including projects from a variety of ownerships and across multiple geographic scales (Swanston et al. 2016). Here, we briefly summarize 2 projects that used the Wildlife Adaptation Menu in conjunction with the Adaptation Workbook during the in-person workshops described above. These are real-world projects that workshop participants were considering prior to the workshops, and the workshop experience allowed them to integrate climate change considerations into their plans. We are featuring these examples because they illustrate varied applications of the menu in terms of focal topic, ownership, and geographic scale. One project is focused on a rare species on public land across a state, whereas the other is concerned more broadly with habitat on a mix of agricultural and natural private land within a specific area.

TABLE 1 Menu of wildlife adaptation strategies and approaches. Strategies are broad adaptation responses that consider ecological conditions and overarching management goals. Approaches are more detailed adaptation responses that articulate different ways that a general strategy could be employed. Professional wildlife managers can use the menu in association with the Adaptation Workbook (Swanston et al. 2016) or other planning processes to define tactics (not represented in the table). Tactics describe specific actions that can be implemented. The full narrative of the menu contains a concise description of each strategy and approach as well as hundreds of example tactics (available online in Supporting Information).

Adaptation strategies	Adaptation approaches and associated references
Adaptation strategies for population management	
1. Maintain and enhance genetic diversity	1.1. Increase genetic exchange between populations[1]
	1.2. Maintain and enhance genetic admixture (interbreeding) zones in order to facilitate adaptive genetic exchange[2,3,4]
	1.3. Limit genetic exchange to protect isolated populations[5]
	1.4. Prioritize conservation of trailing edge or leading-edge populations[6,7]
	1.5. Maintain populations in disturbed environments because they may contain adaptive traits[8,3]
	1.6. Protect areas of high phylogenetic or phenotypic diversity or endemism[9,10]
	1.7. Translocate individuals with climate-adaptive genetic traits[11,12]
	1.8. Preserve genetic material (gene banks)[13,14]
	1.9. Restore genetic diversity in isolated or inbred populations (genetic rescue)[11,15]
2. Establish and maintain connectivity between populations	2.1. Translocate individuals or populations to habitat within the existing range that was formerly occupied and remains suitable (reintroduction)[16,17]
	2.2. Identify and protect source sub-populations[18,19]
	2.3. Establish and maintain connectivity between sub-populations through corridors or stepping stones[20,21]
3. Facilitate shifts in the geographic range of the species in anticipation of future conditions	3.1. Establish corridors and minimize barriers to movement to new suitable habitats[22,23]
	3.2. Prepare suitable habitat in anticipation of future introduction, reintroduction, or natural range shift of a species[24,25]
	3.3. Move and release individuals into a population where conditions are now suitable and are expected to improve[26]
	3.4. Reintroduce species where climate is expected to remain suitable[16,27]
	3.5. Conserve leading-edge populations (high altitude, northern, etc.)[7,28]
	3.6. Introduce species to new areas with suitable current and future climate[17,22,29,30]
4. Manage interspecific and biotic interactions	4.1. Increase or protect existing biodiversity, for example species richness, functional diversity, and phylogenetic diversity[3,31,32]
	4.2. Detect and remove non-native invasive species[33,34]
	4.3. Manage predator populations[35,36,37]
	4.4. Restore historic trophic linkages[35,37]
	4.5. Maintain functional groups or keystone species that help sustain ecosystem functions[38,39]
	4.6. Reintroduce extirpated species or functional groups[17,40]
	4.7. Manage extant and emerging diseases[41,42]

TABLE 1 (Continued)

Adaptation strategies	Adaptation approaches and associated references
5. Maintain a sustainable population size by managing reproduction, survival, and dispersal	5.1. Move and attract individuals to augment an existing population[30,43]
	5.2. Increase reproduction and survival rates[36,44]
	5.3. Use captive breeding programs to increase populations of declining or rare species[17,45]
	5.4. Manage natural predation to increase populations of declining or rare species[46,47]
	5.5. Control take, harvest, and illegal harvest[48,49]
6. Adjust harvest regulations to manipulate populations of harvested species	6.1. Adjust harvest regulations to increase population size for declining species or species anticipated to be impacted by climate change[18,49]
	6.2. Adjust harvest regulations to decrease population size[36,50]
	6.3. Adjust harvest regulations to facilitate shifting phenology or species ranges[51]
7. Plan for and reduce human disturbance and human-wildlife conflict	7.1. Anticipate and manage conflict from increasing populations, range expansions, or changing behaviors[52]
	7.2. Manage conflict associated with societal adaptations to climate change[20,53]
	7.3. Reduce or limit access to sensitive habitats or environments[54,55,56]
	7.4. Reduce or remove human disturbance stress during sensitive time periods[55,57]
	7.5. Implement nonlethal behavioral control methods (barriers and deterrents)[58]
Adaptation Strategies for Habitat Management	
8. Restore, and maintain sources of food, water, and cover as components of habitat	8.1. Manage for plant species diversity and complexity[59,60]
	8.2. Promote plant genetic diversity[61]
	8.3. Prioritize native vegetation and suitable site conditions for habitat management and restoration[60,61]
	8.4. Manage and create suitable microhabitats and microclimates[62,63,64]
	8.5. Enhance primary food sources for specialist climate-sensitive species[25,65]
	8.6. Provide supplemental food sources[66,67]
	8.7. Create or maintain sources of food, water, and cover in a variety of locations across the landscape[68]
	8.8. Maintain or mimic natural disturbance regimes to enhance habitat quality[17,69]
9. Adjust management of food, water, and cover to align with expected future conditions	9.1. Use non-local, future-adapted genotypes in habitat management[61,70]
	9.2. Create new sources of food, water, and cover in anticipation of future conditions[71,72]
	9.3. Accommodate altered hydrology, accounting for periods of high water and low water availability[22,73,74]
	9.4. Maintain or enhance sources of food, water, and cover across the annual cycle and different life stages in response to changing phenology[66,75]
	9.5. Establish or redesign infrastructure to protect habitat from anticipated climate impacts[73,76]

(Continues)

TABLE 1 (Continued)

Adaptation strategies	Adaptation approaches and associated references
10. Establish and enhance protected areas or habitat reserves	10.1. Create large, intact, or aggregated protected areas[22,77,78]
	10.2. Increase representation and replication of protected species and habitats across the portfolio of protected areas[24,77,79]
	10.3. Select reserves that maximize biodiversity protection for a suite of species[3,80]
	10.4. Orient suites of protected areas in ways that span gradients in climate[18,81]
	10.5. Create protected areas that maximize topographic and geologic variety[82,83,84]
	10.6. Protect areas at high risk of change due to climate or land use change[54,85,86]
	10.7. Protect climate refugia across the landscape[56,87,88]
	10.8. Protect sites that are expected to provide future suitable habitat[20,44,78,85]
	10.9. Protect stepping stones, adjacent reserves, and corridors[22,77,89]
	10.10. Create temporary or dynamic reserves[86,90,91]
	10.11. Maintain or enhance habitat across the annual cycle and life stages[21,92]
	10.12. Protect current safe havens for climate vulnerable populations to ensure those populations are available for future conservation efforts[78,93,94]
	10.13. Protect sufficient habitat for viable populations to be self-sustaining and of sufficient quality to create surplus dispersers[33,95,96]
11. Promote wildlife habitat conservation on lands outside of protected areas	11.1. Identify and restore degraded landscapes with high potential habitat quality[17,78,85]
	11.2. Reduce or limit barriers to wildlife movement across private land[97,98]
	11.3. Manage private lands near and between protected lands (buffer zones)[43,97]
	11.4. Enhance green infrastructure and promote sustainable urban landscapes[43,78,99]
	11.5. Manage public or private agricultural land to provide compatible wildlife use[22,97,100,101]
	11.6. Manage forest structure to provide compatible wildlife use[102,103]
Additional Adaptation Strategies	
12. Intentionally choose to take no action	12.1. Take no action in some situations as part of an overall triage strategy[104]
	12.2. Designate no action areas as a control to compare with management interventions[105]
	12.3. Allow for autonomous, or unassisted, adaptation to climate change[17,43]
13. Engage human communities in wildlife conservation	13.1. Develop outreach and technical assistance programs for the public[97,106,107]
	13.2. Provide access for wildlife-dependent recreation[55,108]
	13.3. Increase local community involvement in wildlife management[48,96]
	13.4. Promote community-managed conservation lands[109,110]
	13.5. Respect and incorporate landscape values of indigenous communities in management decisions[111,112]

TABLE 1 (Continued)

Adaptation strategies	Adaptation approaches and associated references
	13.6. Pay for ecosystem services that also benefit wildlife[44,96,113]
	13.7. Coordinate across landowners and scales to make sure programs are complementary[114,115]

Associated references for adaptation approaches: 1: Wong et al. 2013, 2: Ehrlich and Pringle 2008, 3: Webster et al. 2017, 4: Werneck et al. 2012, 5: Russo et al. 2019, 6: Hampe and Petit 2005, 7: Gibson et al. 2009, 8: Linksvayer and Janssen 2009, 9: Dawson et al. 2014, 10: Cobben et al. 2011, 11: Weeks et al. 2011, 12: Prober et al. 2012, 13: Vicente 2010, 14: Fitak et al. 2013, 15: Landa et al. 2017, 16: Kuemmerle et al. 2012, 17: Corlett 2016, 18: Hole et al. 2011, 19: Grinde and Niemi 2016, 20: Jones et al. 2016, 21: Minor and Lookingbill 2010, 22: Kostyack et al. 2011, 23: Howard and Schlesinger 2013, 24: Huntley et al. 2006, 25: Adams-Hosking et al. 2012, 26: Rödder and Schulte 2010, 27: Sax et al. 2013, 28: Thomas et al. 2012, 29: Hällfors et al. 2017, 30: Payne and Bro-Jørgensen 2016, 31: Zimbres et al. 2012, 32: Leadley et al. 2014, 33: Reside et al. 2014, 34: Mainka and Howard 2010, 35: Beschta et al. 2013, 36: Davis et al. 2016, 37: Galetti et al. 2017, 38: Heller and Zavaleta 2009, 39: Kreyling et al. 2011, 40: Dawson et al. 2011, 41: Smith et al. 2009, 42: Walker et al. 2008, 43: Oliver et al. 2012, 44: Poiani et al. 2011, 45: Pritchard et al. 2012, 46: Bradley and Neufeld 2012, 47: Harris et al. 2012, 48: Kingsford et al. 2009, 49: Struebig et al. 2015, 50: Withey and van Kooten 2011, 51: Taillon et al. 2012, 52: White and Ward 2011, 53: Bradley et al. 2012, 54: Raymond and Brown 2011, 55: Schlacher et al. 2013, 56: Gollan et al. 2014, 57: Farhadinia et al. 2015, 58: McClelland 2009, 59: Tilman 1999, 60: Chazdon 2008, 61: Millar et al. 2007, 62: Lagarde et al. 2012, 63: Earl and Semlitsch 2015, 64: Ellis 2015, 65: Regos et al. 2016, 66: Memmott et al. 2010, 67: Maron et al. 2015, 68: Kalda et al. 2015, 69: Wiederholt et al. 2015, 70: Spittlehouse and Stewart 2003, 71: Johnson et al. 2005, 72: Garden et al. 2015, 73: Furniss et al. 2010, 74: Sun and Vose 2016, 75: Hoglander et al. 2015, 76: Rasmussen et al. 2018, 77: Mokany et al. 2013, 78: Fischman et al. 2014, 79: Mawdsley et al. 2009, 80: Barrows and Fisher 2014, 81: Townsend and Masters 2015, 82: Anderson and Ferree 2010, 83: Beier and Brost 2010, 84: Beier et al. 2015, 85: Booth et al. 2013, 86: Leach et al. 2013, 87: Morelli et al. 2016, 88: Ashcroft 2010, 89: Hannah et al. 2007, 90: Rissman et al. 2015, 91: Reynolds et al. 2017, 92: Higuchi 2012, 93: Simmons et al. 2004, 94: Asner et al. 2009, 95: Pontes et al. 2012, 96: Rao et al. 2013, 97: Hamilton et al. 2015, 98: Lister et al. 2015, 99: Vogiatzakis et al. 2016, 100: Gebbers and Adamchuk 2010, 101: Driscoll et al. 2012, 102: Felton et al. 2010, 103: Fassnacht et al. 2015, 104: Hagerman and Satterfield 2014, 105: Zellmer 2012, 106: Yaffee 2011, 107: Blaustein 2013, 108: Shafer 1999, 109: Asare et al. 2013, 110: Brito et al. 2014, 111: Walter and Hamilton 2014, 112: Tribal Adaptation Menu Team 2019, 113: Wiederholt et al. 2015, 114: Marini et al. 2009, 115: Groves et al. 2012.

Adaptation project example no. 1: eastern massasauga rattlesnake management in Wisconsin

The eastern massasauga rattlesnake (*Sistrurus catenatus*, EMR) is a State Endangered Species in Wisconsin, USA, and a Federally Threatened Species. Dependent on large wetlands and floodplain habitats along rivers and streams, EMR primarily occupy open wet meadows, and adjacent upland prairies, forests, and fields. Eastern massasauga rattlesnakes are highly sensitive to impacts of land-use change and climate variability, such as summer flooding (Pomara et al. 2014, Naujokaitis-Lewis et al. 2018). Wildlife managers and conservation biologists from the Wisconsin Department of Natural Resources (DNR) used the Adaptation Workbook and Wildlife Adaptation Menu to develop statewide management strategies to maintain viable populations of this species. More details are available at www.forestadaptation.org/Wisconsin_EMR.

Step 1: Define management goals and objectives

The Wisconsin DNR is focused on preserving viable populations of EMR on 8 extant sites across the state. Management goals across the sites include maintaining open wetland habitat adjacent to upland prairie and forest, maintaining more stable water levels during overwintering periods and spring emergence, and minimizing roadkill. Specific objectives included mowing woody brush during wintertime, conducting springtime dormant-season prescribed fires to maintain open habitats, and mowing road right-of-way areas to <6″ height to deter snakes from crossing.

Step 2: Assess

Biologists considered a range of climate change impacts and vulnerabilities of regional climate change trends for the upper Midwest and how these trends might impact the extant EMR locations in the state. Biologists ranked increasing winter and spring precipitation as one of the highest-priority climate change impacts, due to the concern of flooding and drowning EMRs during overwintering periods. An on-going increase in heavy precipitation events also compounds the risk of flooding EMR burrows. Other notable climate impacts included a potential increase in snake fungal disease under warmer conditions as well as warmer winter conditions leading to false springs and early EMR emergence from hibernation.

Step 3: Evaluate feasibility of management objectives

Next, the project team evaluated the feasibility of their management objectives, considering the climate change impacts that may affect EMR management across the state. The project team identified several challenges that may make their objectives more difficult to accomplish under climate change, such as warmer winter conditions making it harder to access low-lying sites with heavy equipment for mowing or brush control. Earlier springs may compress the allowable window for conducting prescribed fire prior to EMR emergence. Biologists rated the feasibility of their management objectives under current management (no adaptation) from low to high. For example, maintaining more stable water levels during overwintering periods received a low feasibility rating for the floodplain sites, but the project team rated this objective as high feasibility at the poor fen sites with greater ability to manipulate water levels through controlled drawdowns.

Step 4: Identify adaptation approaches and tactics for implementation

The project team used the draft Wildlife Adaptation Menu to identify several adaptation tactics for EMR management across the remaining population sites (Table 2). Reviewing the menu helped the team brainstorm novel adaptation actions to directly address some of their stated climate change risks and feasibility challenges, such as conducting prescribed burns in the winter rather than the conventional spring timeframe. Winter-season burning would have the advantage of avoiding ever-advancing EMR active periods, but prescribed fires in winter may be less effective at controlling woody vegetation. Despite this tradeoff, the project team felt that it was justified to recommend winter-season burning in EMR locations. The team also recognized some adaptation actions in the menu that are already being implemented by the DNR, such as creating large open habitat patches as necessary habitat for EMR. In both cases, the team was able to tier their on-the-ground actions to broader adaptation strategies and ultimately to their management goals, demonstrating thoughtful intent in responding to climate pressures.

Step 5: Monitor and evaluate effectiveness of implemented actions

The project team considered how to evaluate the completion and effectiveness of adaptation actions taken to reach project goals. Useful monitoring efforts identified by the team included tracking the amount of acreage treated per decade through mechanical brush removal and prescribed fire at each EMR population site, EMR population size at

TABLE 2 Selected adaptation tactics the Wisconsin Department of Natural Resources staff identified for eastern massasauga rattlesnake management across remnant population locations in the state. Tactics are associated with specific approaches from the Wildlife Adaptation Menu. A single tactic can fulfill multiple approaches.

Adaptation tactics	Adaptation approaches
Conduct prescribed fires in uplands and wetlands in the winter rather than the spring to avoid EMR activity and take advantage of suitable burn conditions.	9.4 Maintain or enhance sources of food, water, and cover across the annual cycle and different life stages in response to changing phenology
Create large open habitat patches through prescribed fires or mechanical brush removal and mowing.	10.11 Protect habitat across the annual cycle and life stages 10.12 Protect current safe havens for climate vulnerable populations to ensure those populations are available for future conservation efforts 10.13 Protect sufficient habitat for viable populations to be self-sustaining and of sufficient quality to create surplus dispersers
Conduct mark-recapture surveys at all sites to determine source populations of EMR.	2.2 Identify and protect source sub-populations
Mow vegetation along road right-of-way adjacent to EMR sites to deter movement across roads and prevent mortality.	7.1 Anticipate and manage conflict from increasing populations, range expansions, or changing behaviors 7.5 Implement nonlethal behavioral control methods (barriers and deterrents)
Invest in efforts to eradicate non-native plants in EMR population locations and use native seed mixes that are diverse and drought tolerant.	4.1 Increase or protect existing biodiversity, for example species richness, functional diversity, and phylogenetic diversity 4.2 Detect and remove non-native invasive species
Place downed trees around the perimeter of wetland areas for EMR basking locations.	8.7 Create or maintain sources of food, water, and cover in a variety of locations across the landscape

each site, and acres of invasive species treated through various methods. The team created criteria for each monitoring variable to judge effectiveness and discussed how the monitoring could be implemented.

Adaptation project example no. 2: wildlife habitat and sustainable agriculture in the Central Platte River Valley, Nebraska

The Central Platte River in Nebraska, USA, was once a mile-wide braided river with interspersed sandbars and surrounded by grasslands, wetlands, and riparian forests. The landscape has been altered through agricultural land conversion, fire suppression, flood control, and elimination of bison. Yet the riparian corridor still provides critical habitat for wildlife, including approximately half a million sandhill cranes (*Grus canadensis*) during spring migration. Multiple partner organizations worked together at a workshop to envision how sustainable agricultural practices and other climate adaptation strategies could improve habitat in a targeted area of the river valley. More details are available at www.forestadaptation.org/Platte_wildlife.

Step 1: Define management goals and objectives

Staff from The Nature Conservancy, Crane Trust, University of Nebraska-Lincoln, and the Nebraska Game and Parks Commission worked together to develop this project idea, and therefore the management goals represent the overlapping priorities of these organizations. The team focused on a 20-km portion of the Central Platte River Valley southwest of Grand Island, NE. Broadly, the goals of the project are to improve wildlife habitat for cranes and other wildlife, promote habitat-compatible agricultural practices, and demonstrate benefits such as increased cattle forage, greater crop yield, and reduced fertilizer and other input costs to farmers and ranchers in the area. Specific objectives included the following: increasing meadow cover to greater than 30% and reducing woodland cover to less than 30% of the area within 800 meters of the river; increasing average river channel width to over 200 m in the project area; improving soil fertility in agricultural fields; and converting 40% of the row crop fields in the project area to crane-friendly crops such as wheat, barley, and alfalfa.

Step 2: Assess climate change impacts and vulnerabilities

The team reviewed a range of regional climate change trends and how these trends might impact riparian wildlife habitat and agricultural practices in the project area. The team rated warmer winters as the highest-priority climate impact, due to expected changes in crane overwintering patterns, additional shifts in regional wildlife behavior (e.g., earlier greater prairie chicken [*Tympanuchus cupido*] lekking), reduced ice jams that help maintain the river's wide-braided character, and increased pressures from insect pests and cool-season invasive plants. Other notable climate impacts included reduced and more variable snowpack leading to shifting timing of floods and scouring action, as well as more low-streamflow days in the summer facilitating increased vegetation encroachment in the river channel.

Step 3: Evaluate feasibility of management objectives

Team members considered the feasibility of their management objectives under conventional or business-as-usual practices. Climate change is expected to pose several challenges to the management objectives outlined above; for example, altered hydrology and the anticipated increase in irrigation in the project area may benefit woody plant encroachment within the river channel, while reducing hydrological connections between wet meadows and the shallow groundwater that sustains them. Conversely, more frequent floods may support wet meadows and a longer growing season may also facilitate conversion to crane-friendly alternatives to conventional row crops.

Step 4: Identify adaptation approaches and tactics for implementation

Working with the Wildlife Adaptation Menu helped the team express the larger adaptation intent of specific actions and helped individuals representing different organizations convey their ideas and identify common ground. The project team ultimately selected several adaptation approaches that reflected the diverse makeup of the organizations involved (Table 3). Team members that are best positioned to work directly with individual landowners in Central Platte River Valley gravitated toward actions such as establishing cover crops on farm fields to provide a greater variety of wildlife food sources over a longer duration. Other team members are engaged in broader collaborations across multiple agencies, and they identified those interests through adaptation actions such as working with the U.S. Bureau of Reclamation and other river stakeholders to manage for a more natural flow regime with high flows as well as minimum base flows. Managing seasonal flows with an eye toward ameliorating climate-related stressors could help address several of the team's concerns, such as maintaining wetland function and counteracting woody vegetation encroachment.

TABLE 3 Selected adaptation tactics identified by staff from The Nature Conservancy, Crane Trust, University of Nebraska-Lincoln, and the Nebraska Game and Parks Commission for sandhill crane habitat along the Central Platte River Valley in Nebraska, USA. Tactics are associated with specific approaches from the Wildlife Adaptation Menu. A single tactic can fulfill multiple approaches.

Adaptation tactics	Adaptation approaches
Encourage no-till agriculture and cover crops in the Central Platte River watershed. Promote precision agriculture techniques to reduce inputs of fuel, fertilizer, and water.	11.5 Manage public or private agricultural land to provide compatible wildlife use
Replace conventional row crops with native meadow species or alternative crops that may provide a greater variety of food sources over a longer seasonal timeframe.	8.1 Manage for plant species diversity and complexity 9.2 Create new sources of food, water, and cover in anticipation of future conditions 11.3 Manage private lands near and between protected lands (buffer zones)
Identify suitable parcels of private land to protect under conservation easements. Emphasize areas that could be restored to native meadow cover with rest, re-seeding, and tree removal.	10.1 Create large, intact, or aggregated protected areas 10.8 Protect sites that are expected to provide future suitable habitat 8.3 Prioritize native vegetation and suitable site conditions for habitat management and restoration
Establish wildlife-viewing stations and parking lots for tourists to view cranes and other wildlife. Work with local landowners to provide compensation for access.	13.2 Provide access for wildlife-dependent recreation 13.3 Increase local community involvement in wildlife management
Work with the US Bureau of Reclamation and other river stakeholders to manage for a more natural flow regime with high-flow periods as well as a minimum base flow.	9.3 Accommodate altered hydrology, accounting for periods of high water and low water availability
Create disturbances at suitable seasons to boost floristic quality and biodiversity in meadows, such as grazing in the winter and prescribed fire in the summer as opposed to spring.	8.8 Maintain or mimic natural disturbance regimes to enhance habitat quality

Step 5: Monitor and evaluate effectiveness of implemented actions

The project team identified a few monitoring variables that might reveal the effectiveness of the proposed adaptation actions. Monitoring the acres of meadow and woodland in the project area will be critical to track progress toward landcover objectives, in addition to monitoring the acreage of wildlife-friendly agricultural practices being employed. Monitoring the arrival and departure dates of sandhill cranes would help track potential shifts in the migratory pattern and inform the timing of grazing and other actions.

MENU CONSIDERATIONS

The Wildlife Adaptation Menu builds on the tested methods used in creating similar resources to help natural resources professionals develop climate change adaptation plans for forestry, watershed management, forest carbon, outdoor recreation, and urban forestry (Swanston et al. 2016, O'Toole et al. 2019, Shannon et al. 2019, Ontl et al. 2020, Janowiak et al. 2021). It can help advance the field of wildlife management with respect to incorporating specific, intentional actions to adapt to climate change. The iterative process of developing and testing the Wildlife Adaptation Menu helped identify features that the wildlife professionals found useful, even as it revealed improvements that could be made before the next testing session.

The scope and structure are perhaps the most useful features of the menu. The menu captures the full array of concepts related to climate adaptation that are often featured in the scientific literature (LeDee et al. 2021), such as protected area design (Strategy 10), addressing invasive species (Strategy 4), and planning habitat corridors and stepping stones (Strategies 2, 3, and 10). But the menu also contains historically underrepresented management actions, such as managing wildlife diseases (Approach 4.7), survival rates (Strategies 5 and 6), and food sources (Strategies 8 and 9) on equal terms. The unbiased presentation can help managers consider a full range of potential management interventions without being unintentionally influenced by the amount of attention that certain ideas have received. For example, the menu includes numerous adaptation strategies and approaches that emphasize intentional transformation of ecosystems, despite limited adoption of these practices to date.

Organizing the Wildlife Adaptation Menu in a hierarchy of broad strategies with several nested approaches is useful in 2 critical ways. First, it helps users of the menu quickly and efficiently scan the menu (13 strategies, 80 approaches, and hundreds of example tactics) and identify promising pathways to explore. Feedback from our testing workshops emphasized that wildlife managers appreciated this structure. Workshop participants were often searching for particular key words to indicate familiar practices or novel ideas to explore. The feedback helped us express the more general strategies as signposts to attract readers to different topics, such as genetic diversity (Strategy 1), harvest regulations (Strategy 6), and human communities (Strategy 13). Splitting the menu into Population Management and Habitat Management sections also helped managers find adaptation actions within their realm of influence and organizational focus. The menu's organization also helped managers brainstorm new ways to incorporate climate change adaptation into their management situations.

The second benefit of the strategy/approach organizational structure of the Wildlife Adaptation Menu is that it helps managers clearly express the larger intent of the management actions that they design (Swanston et al. 2016). Intentionality refers to the concept that adaptation decisions should be made deliberately to connect management actions with relevant, expected climate impacts (Stein et al. 2014). The menu enables managers to make these connections because the specific tactics that they create are linked to approaches and broader strategies that communicate the larger purpose of the tactic. For example, in the eastern massasauga rattlesnake project summarized above, wildlife biologists from the Wisconsin Department of Natural Resources proposed implementing prescribed fires in the winter rather than the spring, which is the conventional time for the agency to conduct them. Supervisors, partner organizations, and the general public might question the departure from a business-as-usual activity without additional context and a clear idea of intent. The corresponding approach and strategy identify the larger purpose behind the specific action (Approach 9.4: Maintain or enhance sources of food, water, and cover across the annual cycle and different life stages in response to changing phenology; Strategy 9: Adjust management of food, water, and cover to align with expected future conditions.), while potentially opening a conversation about why these adaptations were chosen. In this case, warmer, milder winters are creating new opportunities for prescribed fires, and conducting burns in the winter may reduce the likelihood that rattlesnakes are harmed as their springtime emergence also shifts to earlier in the year.

Manager feedback was critical to the development of the Wildlife Adaptation Menu. Workshop participants helped us improve clarity and limit redundancy across the menu, identify specific tactics to illustrate adaptation approaches, and fill observed gaps in our coverage of the topic. For example, participants encouraged us to make more explicit connections to waterfowl and other migratory species and their demonstration projects provided useful tactics to illustrate several approaches (e.g., Approaches 3.2, 4.4, 6.1, 6.3, 9.2, and 9.4). Managers also promoted and strengthened Strategy 12 (Intentionally choose to take no action). This idea highlights the fact that wildlife professionals work in a context of constrained time and resources, and the approaches underneath this general strategy illustrate that sometimes it can be equally intentional and beneficial to choose not to intervene. Participants at our workshops also encouraged us to retain Strategy 13 (Engage human communities in wildlife conservation) and contributed several ideas to strengthen this section of the menu. Managers stressed the importance of having separate approaches to draw attention to different ways of working with the public (e.g., technical assistance programs, wildlife-dependent recreation, or payment for ecosystem services). This strategy also helped emphasize that input and support from different segments of the public may be beneficial to the overall goal of helping wildlife adapt to climate change (e.g., indigenous communities, neighboring landowners, or outdoor recreationists).

The Wildlife Adaptation Menu has a few potential limitations. First and foremost, the scope of the menu is limited to terrestrial wildlife. Additional literature review and testing would be necessary to fully accommodate fish and other taxa. Additionally, we tested the menu with managers in the Midwest and Great Plains in the United States, so the feedback we received was limited to that context. The participants in our workshops contributed example projects that spanned a wide range of taxa, habitats, and scales, and we intentionally included example tactics from a much wider geography in the full narrative of the menu (Wildlife Adaptation Menu—Complete Narrative with Example Tactics, available in Supporting Information). We hope these efforts have mitigated any potential regional bias, but future workshops with wider audiences may reveal gaps. Another bias inherent in this menu is that ecological features remain the primary focus of adaptation, as opposed to larger societal values (van Kerkhoff et al. 2019). Strategy 13 in the menu includes several approaches that call for broader involvement and participation in wildlife adaptation, but the Adaptation Workbook does not offer specific guidance regarding governance issues that arise when planning for climate change (van Kerkhoff et al. 2019).

Additionally, the menu is based on a recent literature review that captured relevant publications through the year 2017 (LeDee et al. 2021), but climate change adaptation is an area of continued study and rapid development within the field of wildlife management and conservation. As with other adaptation menus, future revisions may be necessary to keep pace with emerging science and management applications (Swanston and Janowiak 2012, Swanston et al. 2016). For example, additional approaches may be necessary to reflect future attention and innovation with respect to intentional ecosystem transition or transformation. The full narrative version of the Wildlife Adaptation Menu contains hundreds of example tactics (Wildlife Adaptation Menu–Complete Narrative with Example Tactics, available in Supporting Information), but the tactics provided are only intended to be prompts for brainstorming, rather than a comprehensive list.

Despite these limitations, the Wildlife Adaptation Menu provides a resource to help wildlife professionals incorporate climate change adaptation into on-the-ground practices. The structure and format of the menu assists managers with brainstorming novel ideas as well as documenting the adaptation benefits of actions that are already familiar. The menu presents an organized list of general strategies and specific approaches that are based on the available scientific literature, and the nested hierarchy helps users move from general to specific ideas. We designed and tested the menu to be used with the Adaptation Workbook planning process, but we think it can be a valuable accompaniment to other adaptation planning frameworks such as the Adaptation for Conservation Targets Framework (Cross et al. 2012), Resist-Accept-Direct (Lynch et al. 2021), or Climate-Smart Conservation (Stein et al. 2014). Pairing the menu with a structured process can provide a basis for intentionally developing management tactics that can help wildlife cope with changing conditions.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

No ethical information provided.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting material may be found in the online version of this article at the publisher's website. We provide the full narrative version of the Wildlife Adaptation Menu, which included concise descriptions of each strategy and approach with relevant citations, as well as example tactics for each approach. We also provide a sample agenda from one of our workshops, which were used to test the menu with wildlife managers. Finally, we provide an example questionnaire used to solicit feedback from workshop participants.

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