

ARTICLE

Resist-accept-direct (RAD) considerations for climate change adaptation in fisheries: The Wisconsin experience

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Abstract

Decision-makers in inland fisheries management must balance ecologically and socially palatable objectives for ecosystem services within financial or physical constraints. Climate change has transformed the potential range of ecosystem services available. The Resist-Accept-Direct (RAD) framework offers a foundation for responding to climate-induced ecosystem modification; however, ecosystem trajectories and current practices must be understood to improve future decisions. Using Wisconsin's diverse inland fisheries as a case study, management strategies for recreational and subsistence fisheries in response to climate change were reviewed within the RAD framework. Current strategies largely focus on *resist* actions, while future strategies may need to shift toward *accept* or *direct* actions. A participatory adaptive management framework and co-production of policies between state and tribal agencies could prioritise lakes for appropriate management action, with the goal of providing a landscape of diverse fishing opportunities. This knowledge co-production represents a process of social learning requiring substantial investments of funding and time.

Authors contributed equally to the development of this manuscript. Author order after the first author was decided randomly in R using:

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KEYWORDS

climate change, co-production, fisheries management, inland fisheries, RAD framework, social-ecological systems

1 | INTRODUCTION

Inland fisheries provide food, recreation, economic support, and a vital connection to nature for people driven by an array of motivations, including harvest-oriented recreational anglers, high-effort trophy anglers, and casual anglers. Culturally important, traditional tribal subsistence fisheries also exist in many inland waters. Therefore, the management of inland fisheries is complex, as decision-makers are required to balance ecologically and socially palatable objectives for multiple groups within financial and physical constraints (Lynch et al., 2021; Thompson et al., 2021). Climate change has altered the balance between social and ecological tradeoffs and transformed ecosystem services, requiring managers, tribes, and the public to adapt to changing circumstances (Myers et al., 2017; Tingley et al., 2019b). The Resist-Accept-Direct (RAD; Schuurman et al., 2022) framework offers a useful foundation for decision-makers to address climate change-induced ecosystem modification. Is it possible to *resist* ecosystem change and maintain current or historical services, or should ongoing change be *accepted* as a new baseline? If decision-makers can predict where an ecosystem is headed, can they *direct* the ecosystem or communities of use to take advantage of the emergence of new services? To address these questions, tribal perspectives, legacy and current management practices, stakeholder attitudes, and ecosystem trajectories must be viewed such that decision-makers learn how RAD approaches have worked in the past and how RAD approaches can be formally integrated into decision-making in the future (Lynch et al., 2022; Rahel, 2022).

The aquatic ecosystems of Wisconsin feature several of the issues outlined above—abundant and diverse water bodies, dynamic resource users, and multiple managers, including state and tribal natural resource agencies (Pereira & Hansen, 2003; Rypel et al., 2019; US Department of the Interior, 1991). Important inland fisheries range from coldwater stream trout, including brook trout/maazhamegoons *Salvelinus fontinalis* (Mitchill) and brown trout/namegos *Salmo trutta* Linnaeus, to coolwater and warmwater species in lakes, like muskellunge/maashkinoozhe *Esox masquinongy* Mitchill, walleye/ogaa *Sander vitreus* (Mitchill), largemouth bass/ashigan *Micropterus salmoides* (Lacépède), and bluegill/agwadaashi *Lepomis macrochirus* Rafinesque (Embke et al., 2020; Feiner et al., 2020b; Mrnak et al., 2018; Figure 1). Throughout this paper Ojibwe names for fish beings/species will also be used, but please note that other tribes in Wisconsin (e.g., Ho-Chunk, Menominee) have their own languages and words for their fish relatives. Climate change poses multiple threats to the stability and services of Wisconsin inland fisheries (Craig et al., 2017). Warming waters alter the distribution of thermally-suitable habitats for cool and coldwater species (Eaton & Scheller,

1996; Renik et al., 2020). For instance, brook trout/maazhamegoons and brown trout/namegos are projected to lose upwards of 68% and 32% of their current suitable habitat, respectively, in Wisconsin by the mid-21st century (Mitro et al., 2019). Likewise, lake whitefish/adikameg *Coregonus clupeaformis* (Mitchill) and cisco/odoonibiins *C. artedii* Lesueur have been extirpated from 30% and 33% of inland lakes in Wisconsin with a historical record of their presence, respectively (Renik et al., 2020), with cisco/odoonibiins predicted to lose an additional 30–70% of their remaining inland populations (Sharma et al., 2011). Walleye/ogaa and potentially yellow perch/asaawe *Perca flavescens* Mitchill recruitment is declining (Brandt et al., 2022; Rypel et al., 2018). Climate change and interactions with warmwater species are the leading hypothesised causes (Hansen et al., 2015b, 2017; Sullivan et al., 2020), although production over harvest and land-use change (e.g., loss of natural shorelines) are being recognised as interacting drivers (Embke et al., 2019; Jacobson et al., 2019). Many lake fish communities may therefore be shifting from coldwater/coolwater assemblages, which support some of the most popular sport fishes in the state, to warmwater communities as species like black basses and sunfish increase in abundance. Indeed, Wisconsin Department of Natural Resources (WDNR) lake classes defined to represent fish assemblages and their associated lake habitats (Rypel et al., 2019) have begun to shift from cool to warm classifications, and WDNR projections forecast a near-complete loss of cool lakes by the end of the century (A.W. Latzka, WDNR, unpublished data). Beyond changes in habitat, losses of winter ice are yielding uncertain outcomes for ice fishing (Sharma et al., 2020), historically a period of high effort in Wisconsin (Feiner et al., 2020b). Climate change also threatens to exacerbate the risks of other stressors like heat-induced fish kills (Till et al., 2019), range expansions of invasive species (Walsh et al., 2020), and more frequent and extreme floods (Dauwalter & Mitro, 2019; Gudmundsson et al., 2021), which can substantially threaten valuable native fish communities.

Climate change portends considerable and complicated shifts in the social-ecological dynamics of a Wisconsin fisheries landscape that supports about 14,000 jobs and provides \$1.9 billion in annual economic output (American Sportfishing Association, 2020), in addition to about 4,200 metric tons of wild fish harvested by anglers for consumption annually (Embke et al., 2020). The emergence of new fisheries could offer exciting, unique opportunities for some anglers, while others struggle to adjust or leave the fishery entirely (Tingley et al., 2019a). Similarly, competing interests of entities with different motivations and priorities must be considered. For example, a relatively unique joint fishery exists in the Ceded Territories of Wisconsin (CTWI; approximately the northern third of the state; Staggs et al., 1990) where sovereign tribes retain traditional fishing rights and fisheries are jointly managed by state and



FIGURE 1 Wisconsin offers diverse recreational (a–c, f–j) and tribal (d, e) fisheries in all seasons, from coldwater trout streams to warmwater rivers and lakes. Climate change threatens to alter fishing opportunities across the state and therefore complicate fisheries management, as habitats transition from supporting cold and coolwater fisheries to warmwater species. Top row: (a) brown trout/amegog (credit: Matthew Mitro), (b) brook trout/maazhamegog (credit: Matthew Mitro), (c) walleye/ogaa caught in the recreational ice fishery (credit: Greg Sass), (d) tribal walleye/ogaa spearing (credit: Charlie Rasmussen), and (e) muskellunge/maashkinoozhe speared during tribal harvest (credit: Charlie Rasmussen). Bottom row: (f) cisco/odoonibiins (credit: Zachary Feiner), (g) yellow perch/asaawe caught ice fishing (credit: Greg Sass), (h) bluegill/agwadaashi (credit: Cassie Kolstad), (i) largemouth bass/ashigan (credit: Amanda Kerkhove), and (j) black crappie/gidagagwadaashi (credit: Greg Sass)

TABLE 1 Examples of current or prospective RAD strategies for climate adaptation in Wisconsin fisheries with relevant references

Resist	Accept	Direct
Fish stocking: Walleye/ogaa ^{1–3} Lake trout/amegog ^{4,5} Brook trout/maazhamegog ⁶	Allow inland cisco/odoonibiins and lake whitefish/adikameg declines without intervention ^{7,8}	Development of warmwater fishing opportunities in changing lakes ^{9,10}
Walleye/ogaa harvest management ^{11–14}	Cessation of stocking in walleye/ogaa lakes with low probability of success ^{15,16}	
Species removals and controls: Centrarchids ¹⁷ Bullheads ¹⁸ Brown trout/amegog Bass (via liberalised regulation) ¹⁹	Allow warmwater species (e.g., largemouth bass/ashigan, bluegill/agwadaashi) expansions and increases in abundance ^{19,20}	
Walleye/ogaa rehabilitation plans ^{21–23}		
Riparian land-use management to protect trout streams ^{6,24,25}		
Protection of “bright spots”: Brook trout/maazhamegog reserves ⁶ Walleye/ogaa ¹⁵		

Note: ¹WDNR, (2020), ²Hansen et al., (2015a, 2015b), ³Grausgruber & Weber, (2020), ⁴Piller et al., (2005), ⁵Parks & Rypel, (2018), ⁶WDNR, (2019), ⁷Renik et al., (2020), ⁸Sharma et al., (2011), ⁹Tingley et al., (2019a), ¹⁰Tingley et al., (2019b), ¹¹Haglund et al., (2016), ¹²Embke et al., (2019), ¹³Rypel et al., (2015), ¹⁴Tseyhaye et al., (2016), ¹⁵Dassow et al. concurrent submission, ¹⁶Lawson et al. in press, ¹⁷Embke et al. concurrent submission, ¹⁸Sikora et al., (2021), ¹⁹Sullivan et al., (2020), ²⁰Hansen et al., (2015a, 2015b), ²¹Shultz et al., (concurrent submission), ²²Bajenske et al., (2021), ²³WDNR, (2021), ²⁴Cross et al., (2013), ²⁵Gaffield et al., (2005).

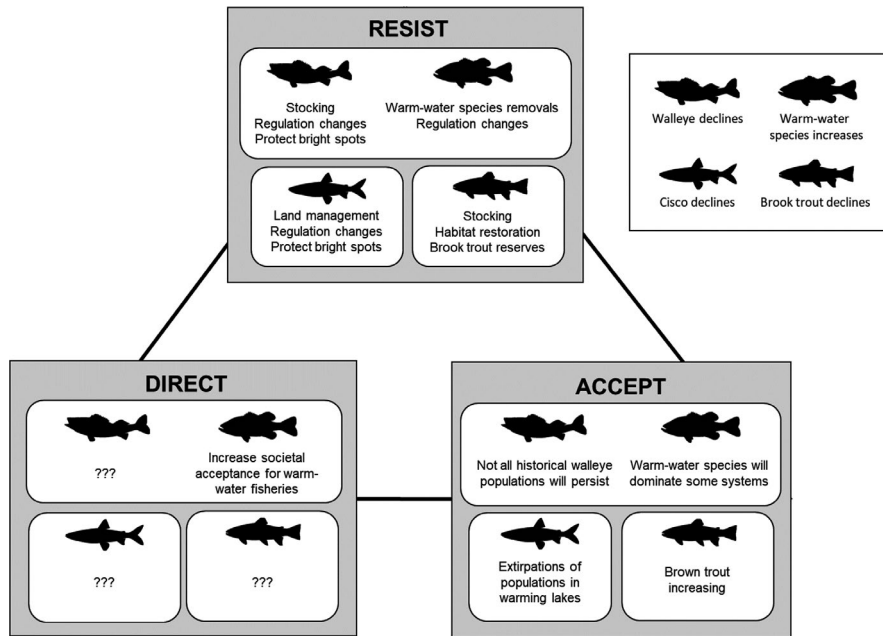


FIGURE 2 Examples of potential Resist-Accept-Direct management strategies for important inland Wisconsin fisheries (walleye/ogaa, cisco/odonnibins, brook trout/maazhamegoons, and warmwater species like largemouth bass/ashigan). Current strategies largely *resist* ecosystem change by stocking, harvest regulation, and land-use management but may need to incorporate alternative *accept* and *direct* approaches to reconcile fisheries shifts

tribal entities to balance recreational demand and treaty obligations to tribal harvest (US Department of the Interior, 1991). Here, it is important to note that tribal and state perspectives on fisheries differ – the state views its role as a resource manager, which implicitly suggests dominance over natural resources in the state. The tribes view fisheries as natural gifts and their interaction with these fishes/giingonyag as a relationship between equals (Shultz et al., concurrent submission). These diverse worldviews need to be considered when making decisions about fisheries gifts and how to share them among recreational anglers and citizens of sovereign tribal nations. Given these complexities, how should managers approach a highly dynamic social-political-ecological landscape to provide a mosaic of opportunities that meet the needs of a diverse fishing population while attempting to maintain sustainable fishery resources? The RAD framework offers guidance, but first, a better understanding of how current strategies and fish-human relationships in Wisconsin are aligned in the RAD framework is needed. Such an approach can be vital for envisioning novel ways to think about the relationship between fish and people in the face of climate change.

This paper provides an overview of current and potential future management strategies for Wisconsin's inland recreational and tribal fisheries in response to climate change, placed within the RAD framework (Table 1). Many current actions are focused on strategies to *resist* ongoing changes, while future strategies may need to *accept* or *direct* change to achieve palatable (figuratively and literally) outcomes for state and tribal fishers (Lynch et al., concurrent submission; Rahel, 2022). Balancing the desires and needs of recreational and tribal interests can result in alternative policies depending on location, and the co-production of policies in the face of climate change will be paramount to meet the needs of recreational and tribal fishers (Jackson, 2021). An examination of future concerns and needs to fully understand the ability and willingness of recreational

and tribal fishers to adapt to coming changes to the Wisconsin fishing landscape is provided, which will be crucial to devising strategies that will be acceptable for fish and people given global environmental change.

2 | RESISTING ECOSYSTEM CHANGE

To date, fisheries management in Wisconsin has largely focused on *resisting* the influences of climate change by striving to maintain existing ecosystem composition, structure, and services (Lynch et al., 2021; Schuurman et al., 2020). Like many states, Wisconsin's climate adaptation plans for natural resource management have lagged behind rapid ecosystem change, despite previous attempts to be proactive (Wisconsin Initiative on Climate Change Impacts, 2011). Recent directives by the State of Wisconsin (2020) have reinvigorated attention to climate change and working groups have convened to develop climate adaptation strategies (Magee et al., 2019; Tingley et al., 2019b; Wisconsin Initiative on Climate Change Impacts, 2021). However, current resistance policies, despite novel effects of climate change, are likely legacy effects of past resistance efforts that were effective or presumed to be effective. Therefore, most current resistance strategies in Wisconsin have aimed to sustain historical fisheries using tools within managerial control (i.e., Carpenter et al., 2017). The three most prominent examples of resistance strategies that are currently employed in Wisconsin and focused on below are (i) walleye/ogaa management, including stocking, harvest regulations, large-scale population rehabilitation, and biomanipulations, (ii) lake trout/namegos (*Salvelinus namaycush* Walbaum) stocking, and (iii) brook trout/maazhamegoons conservation via stocking, habitat management, and non-native trout control. In the future, these and other strategies could be assisted by identifying and prioritising “bright spots” (i.e., stronghold populations of declining fish species;



Bennett et al., 2016), which is discussed as a framework for orienting management activities with the goal of ensuring at least some populations of brook trout/maazhamegoons, walleye/ogaa, and cisco/odoonibiins remain on the landscape for the foreseeable future (Figure 2).

2.1 | Walleye/ogaa management and rehabilitation

Climate change has been implicated in walleye/ogaa declines by degrading habitat (Hansen et al., 2017, 2019) and shifting fish community composition toward warmwater species dominance (Hansen et al., 2015a, 2015b; Sullivan et al., 2020). Potential production overharvest has also deteriorated walleye/ogaa stocks (Embke et al., 2019; Sass et al., 2021). Given the cultural importance and harvest-oriented nature of walleye/ogaa fisheries in the CTWI (Gaeta et al., 2013; US Department of the Interior, 1991), climate adaptation is challenging because policies to accept or direct change are not often politically, culturally, and recreationally palatable to management agencies, tribal nations, anglers, and stakeholder groups (Nesper, 2002). Thus, resistance strategies continue to dominate the management of walleye/ogaa in Wisconsin (Dassow et al., concurrent submission; Hansen et al., 2015a, 2015b; Tingley et al., 2019b).

The two most common strategies implemented in the face of walleye/ogaa declines are stocking and harvest management. Walleye/ogaa stocking is common throughout Wisconsin, but stocking of fry and small fingerlings (~100 mm total length) has sometimes been met with limited success. In response, the Wisconsin Walleye Initiative (WWI; WDNR, 2020) was established in 2014 as a substantial investment to fiscally support WDNR, tribal, and private hatchery infrastructure to raise extended growth walleye/ogaa (EGW) fingerlings (~175–200 mm total length) for stocking in lakes with the highest probability of supporting natural recruitment (Hansen et al., 2015a). Stocking of EGW was assumed to lead to greater survivorship over fry or small fingerlings owing to their larger length (Graumgruber & Weber, 2020). However, preliminary results suggest that EGW mortality rates are often high and variable (Lawson et al., in press; Tingley et al., 2019b), exacerbated by stress associated with transport and difficulty in transitioning to natural prey (Graumgruber & Weber, 2021a, 2021b). Raising EGW may also lead to skewed sex ratios (up to 100% female) using common hatchery protocols, which could hinder efforts to rehabilitate natural recruitment by limiting the effective population size of reproducing adults via mate scarcity (Sass et al., 2022). Because of the resources invested in producing and stocking EGW, further examinations of the success of EGW stocking are needed (Lawson et al., in press).

Coincident with changes in stocking practices, harvest regulations for walleye/ogaa in the recreational fishery have become more restrictive. Prior to 2015, most walleye/ogaa fisheries were managed with a 381-mm minimum length limit and a daily bag limit of five fish, which appeared sustainable when natural recruitment was consistently replenishing walleye/ogaa populations (Fayram et al.,

2001; Sass et al., 2004). However, recent reductions in walleye/ogaa production and recruitment may have made previously allowable exploitation unsustainable (Embke et al., 2019; Rypel, 2015; Tsehay et al., 2016). Responding to walleye/ogaa declines, CTWI regulations now consist of a 381-mm minimum length limit, 508–610-mm protected no harvest slot length limit, and a daily bag limit of three fish with only one fish allowed >610 mm. This regulation was aimed to reduce exploitation and to protect large female walleye/ogaa, which may disproportionately contribute to age-0 recruitment (Feiner et al., 2019; Shaw et al., 2018). In the tribal subsistence walleye/ogaa spearfishery, males are primarily available for harvest, and larger females are protected by conservative harvest regulations (Mrnak et al., 2018). The effectiveness of the current recreational angling regulation to reduce exploitation and improve natural recruitment has not been rigorously evaluated; however, it will be tested as a new regulation on formerly unexploited Escanaba Lake, Wisconsin, beginning in summer 2022 (Haglund et al., 2016). Although responses to stocking and harvest restrictions have been uncertain, these resistance strategies are likely to continue due to biologist, angler, tribal member, and stakeholder perceptions of effectiveness and hatchery infrastructure investments, despite generally poor outcomes (Lawson et al., in press; Sass et al., 2017).

A more organized and concentrated example of resistance in Wisconsin walleye/ogaa management is the development of numerous walleye/ogaa rehabilitation plans for historically quality fisheries that have declined since the early 2000s (WDNR, 2021). In the CTWI, walleye/ogaa rehabilitation plans have been co-produced with input from the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), tribes, WDNR, lake associations, and conservation organizations (e.g., Walleyes for Tomorrow). Although plans often used the term “restoration,” partners realised that restoring the ecosystem back to its historical state was unlikely for most lakes, thus the term “rehabilitation” was adopted instead (Bajenske et al., 2021). Initially, these plans took a two-pronged approach to rehabilitate walleye/ogaa stocks that included harvest reductions and stocking. Harvest reductions were pursued by implementing highly restrictive regulations, including catch-and-release only or a daily bag limit of one fish over 711 mm for recreational anglers along with reductions or complete cessation of tribal harvest. Concomitantly, consistent stocking of juvenile and occasionally adult fish (e.g., Kentuck Lake History Team, 2001) were used to bolster declining adult walleye/ogaa populations.

Walleye/ogaa rehabilitation plans have been met with mixed success. In some lakes, walleye/ogaa stocks have increased and natural reproduction has been reestablished; in others, adult stocks increased, but recruitment remained nonexistent; and in a few lakes, rehabilitation has failed to improve adult or juvenile abundances (Bajenske et al., 2021; Kentuck Lake History Team, 2001). Reasons for variation in success are unclear. However, rehabilitation plans may not meet goals when natural recruitment was not limited by reduced stock sizes but by other factors (e.g., habitat change, fish community shifts, or compensatory recruitment; Sass et al., 2021). In

response to such variable results and success rates, partners have adapted rehabilitation plans to include social and ecological components, including recovery of sustainable fishing opportunities, clear evaluation timelines and measures of success, public outreach and reporting, lake-specific habitat management, and current and future projections of the fish community incorporating climate change predictions (Midwest Glacial Lakes Partnership, 2019; WDNR, 2021). Though met with uncertain success rates, these rehabilitation plans are a prime example of communities implementing labor- and capital-intensive resistance strategies when faced with the decline of a culturally and recreationally important fishery.

Finally, as an example of an extreme resistance strategy to rehabilitate walleye/ogaa populations, intensive fish removals have been conducted on a few lakes in northern Wisconsin (Embke et al., concurrent submission; Sikora et al., 2021). Climate change, conservative harvest regulations, and predominant catch-and-release practices by anglers have resulted in increased largemouth bass/ashigan abundances in Wisconsin lakes over time (Hansen et al., 2015a, 2015b; Sass & Shaw, 2020), which may also reflect general increases in centrarchid abundances (Feiner et al., 2020b; Rypel et al., 2016). Similar increases have been observed for bullhead *Ameiurus* spp. (Sikora et al., 2021). Changes in fish community composition and dominance have been implicated in the decline of naturally recruiting walleye/ogaa populations, although mechanisms remain unclear (Embke et al., concurrent submission; Kelling et al., 2016; Sullivan et al., 2020). In response, several whole-lake bullhead or centrarchid removal experiments have been conducted to reduce predation/competition to favor walleye/ogaa. Whole-lake bullhead removals on four northern Wisconsin lakes showed improvements in walleye/ogaa natural recruitment, stocked walleye/ogaa survival, and adult density. Bullhead removals also shifted fish community dominance to favor walleye/ogaa and yellow perch/asaawe (Sikora et al., 2021). Currently, a whole-lake centrarchid removal (Embke et al., concurrent submission) and another whole-lake bullhead removal (Sikora et al., 2021) are ongoing to test for mechanisms leading to fish community change. Although whole-lake fish removals may be effective in restoring walleye/ogaa natural recruitment and former percid dominance, feasibility, effort, expense, and social acceptability might prevent this strategy from broad use as a resistance strategy against climate change (Embke et al., concurrent submission). Further, the long-term viability and effectiveness of these removal resistance strategies are unknown. If thermal and habitat conditions continue to favor centrarchid and bullhead dominance, these species would be predicted to return to dominance over time without additional maintenance removals or other interventions, such as habitat conservation or enhancement.

2.2 | Preserving inland lake trout/namegos

Lake trout/namegos are native to two inland lakes in Wisconsin (Trout Lake and Black Oak Lake, Vilas County). Each population represents a unique genetic strain from one another and Lake Superior,

making these populations important for conservation as the last indigenous inland lake trout/namegos populations in the Upper Mississippi River basin (Parks & Rypel, 2018; Piller et al., 2005). Lake trout/namegos rely on the availability of cold, well-oxygenated habitats (Plumb & Blanchfield, 2009), which are projected to decline in southern parts of their historical range with climate change (Minns et al., 2008). In addition, the Trout Lake population has struggled to produce natural recruits for several years and low levels of natural recruitment occur in Black Oak Lake (Parks & Rypel, 2018; Piller et al., 2005). Management for conservation of inland lake trout/namegos in Wisconsin has solely relied on stocking using lake-specific broodstock to maintain their genetic distinctness (Piller et al., 2005). Trout Lake is currently stocked every two years, while Black Oak Lake was stocked in 2017–2018 for the first time since 1980 (Parks & Rypel, 2018; Piller et al., 2005). Unlike other lake-rich regions such as Minnesota (e.g., Jacobson et al., 2013), relatively little attention has been paid to resistance management to conserve coldwater lacustrine habitats through watershed conservation efforts. Minnesota coldwater resource management has focused on conserving the most climate-resilient lakes through watershed degradation prevention (Jacobson et al., 2013), which could form the basis for an additional strategy to resist loss of coldwater habitat in Wisconsin (see also section on *Direct* strategies).

2.3 | Resisting stream trout/maazhamegoons loss through stocking, land management, and removals

Native brook trout/maazhamegoons and introduced brown trout/namegos are coldwater species that support stream fisheries across Wisconsin. Both species rely on coldwater temperatures (Lyons et al., 2010; Wehrly et al., 2007), sustained groundwater inputs (Lyons et al., 2009), and a natural hydrologic regime conducive to recruitment, growth, and survival. Rising air temperatures in Wisconsin associated with climate change (Kucharik et al., 2010; Wisconsin Initiative on Climate Change Impacts, 2011) are projected to result in significant declines in suitable thermal habitat for stream trout (Mitro et al., 2019), and increases in the frequency and intensity of floods during key life-history periods like winter or spring are likely to result in negative impacts to trout recruitment or adult trout survival (Dauwalter & Mitro, 2019; Letcher et al., 2015; Zorn & Nuhfer, 2007). Resistance strategies for maintaining trout fisheries in streams when threatened by loss of habitat have focused on stocking, habitat restoration or development, and land-use management at the watershed scale.

Under current guidelines, trout are stocked in Wisconsin streams to: (i) restore naturally-reproducing native brook trout/maazhamegoons populations; (ii) maintain trout fisheries where natural reproduction is insufficient to do so; and (iii) create put-and-take trout fisheries where the habitat does not support inter-annual survival. Stocking can be prioritised with consideration of climate change effects on stream condition (WDNR, 2019), and a growing body of Wisconsin-based research is actively working

to identify fish populations or streams particularly vulnerable to changing climate conditions (e.g., Mitro et al., 2019; Westenbroek et al., 2012) to help guide future stocking decisions. Since 2015, brook trout/maazhamegoons and brown trout/namegos have been stocked in 319 and 275 streams and rivers, respectively, and climate change may foster conditions that necessitate expanded stocking to maintain trout fisheries. For example, if ill-timed flood events lead to year-class failures in successive years, or if thermal conditions change such that warm periods preclude inter-annual survival, stocking may be necessary to maintain fisheries. Although summer maximum water temperatures may prohibit the occurrence of wild trout populations in more and more streams as the climate continues to warm (Mitro et al., 2019), seasonally coldwater temperatures will persist for the foreseeable future in Wisconsin such that put-and-take stocking can continue to be a viable resistance strategy to maintain the availability of coldwater trout fisheries on the landscape (Mitro et al., 2019).

Although not in direct response to climate change effects on trout, restorations of instream and riparian habitat and management of watershed land use demonstrate how current management practices can also act as strategies to resist climate change impacts. For example, in the Driftless Area of western Wisconsin, heavy equipment is used to stabilise and reconnect eroded streambanks to floodplains, and install instream habitat and bank cover structures. Such management of habitat has built resistance to climate change by enhancing population abundance, survival, and reproductive capacity (Schuurman et al., 2022), protecting streambanks from erosion by large-scale floods and preserving cold thermal regimes. Watershed-scale management has been pursued across the state and includes promoting best management practices in agricultural land use such as no-till or contour plowing for row crops, rotational grazing of grasslands, enrollment of environmentally sensitive lands in the Conservation Reserve Program, public acquisition of private lands for protection, and limiting impervious surfaces to reduce erosion and facilitate groundwater infiltration. Cold groundwater inputs to streams are critical to maintaining cold thermal conditions suitable for trout (Lapides et al., 2022), and improvements in land use to improve groundwater recharge have been instrumental in recovering coldwater streams in the Driftless Area, which is now projected to be a region of high resistance and resilience to climate warming (Mitro et al., 2019). Stream channel restoration has been used to narrow and deepen channels to help conserve coldwater as it flows downstream, and riparian shading has helped further maintain coldwater temperatures in streams (Cross et al., 2013; Gaffield et al., 2005). Stream fish passage via culvert replacement has also been prioritised in northern and southern Wisconsin to improve connectivity and migration and to reduce thermal pollution (Neeson et al., 2018; O'Hanley et al., 2013; WDNR, 2019). Instream habitat development has helped bolster trout populations (Avery, 2004; Hunt, 1976, 1988), but habitat projects perhaps best resist effects of climate change by buffering stream temperatures to warming summer air temperatures and by protecting streambanks from erosive forces of intense rain events.

While resistance strategies are being used to protect or maintain trout fisheries where the alternative is no trout fisheries, resistance strategies are also being used to protect or maintain native brook trout/maazhamegoons from replacement by introduced brown trout/namegos. Nonnative brown trout/namegos often replace, or become dominant over, native brook trout/maazhamegoons where they coexist (Budy & Gaeta, 2017; Waters, 1983). Brown trout/namegos dominance over brook trout/maazhamegoons likely results from numerous factors, namely competitive advantages of brown trout/namegos that lead to differences in survival or reproductive success or stream habitat degradation that favors more thermally tolerant brown trout/namegos over brook trout/maazhamegoons (Eaton et al., 1995; Wehrly et al., 2007). Optimal thermal temperatures for brown trout/namegos are slightly warmer than those for brook trout/maazhamegoons (Behnke, 2002). With climate change projected to decrease distributions of both trout species (Mitro et al., 2019), interactions between brook/maazhamegoons and brown trout/namegos are likely to change in complex ways (Valerie & Daniels, 2021) and will likely favor brown trout/namegos over brook trout/maazhamegoons in some regions without direct interventions. Accordingly, resistance actions (e.g., brown trout/namegos removals) have been applied in many watersheds to bolster brook trout/maazhamegoons populations. For example, brown trout/namegos removals from Maple Dale Creek in Vernon County, Wisconsin, led to large increases in brook trout/maazhamegoons abundance (WDNR, unpublished data). Thus, there is growing evidence that climate change resistance strategies can help native trout species threatened by non-native salmonids (Budy et al., 2021; Pacas & Taylor, 2015).

2.4 | Protecting the bright spots

In the future, the implementation of strategies to resist system change in Wisconsin fisheries could shift toward the management of resources, rather than ecosystems, to consider fisheries management at the landscape scale. Although climate change poses significant risks to the state's fisheries, the sheer diversity of ecosystems (e.g., lake classes; Rypel et al., 2019) offers opportunities to identify and protect "bright spots"—places where extant fish communities are providing desired services now and are projected to continue to do so in the future (Cinner et al., 2016). A bright spots approach has two attractive attributes. First, identifying positive "outliers" can reveal fish-people relationships that have resulted in resilient, productive fisheries potentially leading to improved practices to rehabilitate other struggling systems (Bennett et al., 2016; Cinner et al., 2016). Second, demonstrating effective protection and management of important, visible resources can improve public trust and perceptions of management strategies and inspire optimism for future management actions (Cvitanovic & Hobday, 2018). However, identifying bright spots, understanding the mechanisms driving their characteristics, and implementing effective management policies will require the combination of basic

scientific research and social-ecological outreach before yielding such benefits (Cvitanovic & Hobday, 2018). At the landscape scale, bright spots protection could thus act as a strategy to resist change in some lakes while others are allowed to (or are managed to) change, thereby maintaining a socially acceptable level of diversity in fishing opportunities.

Current examples of this management strategy are sparse in Wisconsin; however, some initial actions to identify bright spots have been implemented. For example, the Brook Trout/maazhamegoons Reserves Program was recently initiated to identify subwatersheds (at the Hydrological Unit Code [HUC] 12 scale) that support quality, genetically diverse brook trout/maazhamegoons populations that are resilient to climate warming and environmental perturbations. To accomplish this, WDNR identified 54 candidate reserves grouped into four future vulnerability classes (based on a 95% threshold for the amount of riparian buffer covered by natural vegetation and a 19°C threshold for future July mean water temperature) with associated management themes: (1) resilient and secure—monitor and protect; (2) resilient and possibly secure—monitor and improve riparian buffers; (3) vulnerable with strong opportunities for improvement; and (4) vulnerable with limited opportunities for improvement. These classes can be used to guide agency resources and develop watershed-specific management strategies and recommendations regarding stocking, instream or riparian habitat improvement, land acquisition, watershed land use, groundwater protection, and public outreach (WDNR, 2019).

A bright spots approach could also be used in future walleye/ogaa rehabilitation efforts. As discussed above, stocking currently comprises a significant amount of time and monetary resources in Wisconsin fisheries management but has been met with variable success. However, there are some systems where stocking and harvest restrictions have considerably improved or rehabilitated walleye/ogaa population (e.g., Kentuck Lake History Team, 2001). Understanding the dynamics occurring in these rehabilitation bright spots that led to improved stocking success could be used to orient limited stocking resources toward systems where the likelihood of successful maintenance or rehabilitation of walleye/ogaa is more likely. Management in systems where conditions are unfavorable for rehabilitation success could then use *accept* strategies for the improvement of fisheries for other species that are projected to thrive. A similar bright spots framework is currently being used to prioritise the protection of cisco/odoonibiins populations in Minnesota that could be applied in Wisconsin lakes as well (Jacobson et al., 2013). Clear difficulties are associated with implementing these practices. Nevertheless, the WDNR and GLIFWC have begun to include resilience to climate change as an important factor in future management decisions (Donofrio et al., 2020; Panci et al., 2018). Adopting a “bright spots” framework could allow for a more efficient distribution of limited management resources, while expanding knowledge of the conditions under which walleye/ogaa rehabilitation or cisco/odoonibiins persistence is more likely.

3 | ACCEPTING ECOSYSTEM CHANGE

For many cool- and coldwater species, climate change will likely result in the loss of appropriate habitat, particularly in systems that already provide marginal habitat (Rypel et al., 2019). Thus, the effort required to maintain threatened populations will likely follow a gradient from populations where relatively little intervention is required to those that may not be maintainable even with intensive management (e.g., Embke et al., concurrent submission). The placement of populations along this gradient can aid in allocating limited management resources at the landscape scale, maintaining populations likely to persist while identifying populations where *accepting* declines or losses might represent the most logical management response (Lynch et al., 2022; Figure 2).

3.1 | Losses of cisco/odoonibiins, lake whitefish/adikameg, and walleye/ogaa

In Wisconsin, acceptance strategies may be most exemplified by the management of inland populations of cisco/odoonibiins and lake whitefish/adikameg, which are projected to lose substantial habitat due to climate change in Wisconsin (Sharma et al., 2011). Current practices have largely monitored, but accepted, losses of cisco/odoonibiins and lake whitefish/adikameg populations in many lakes without intervention (Renik et al., 2020). However, identifying lakes that may be more resilient to climate change influences could help prioritise future strategies. In Minnesota, for example, Jacobson et al. (2008) identified oxy-thermal habitat boundaries for cisco/odoonibiins in inland lakes. Fang et al. (2012) simulated future habitat conditions and classified lakes into three tiers based on the probability of cisco/odoonibiins occurrence, which included a tier of lakes identified as nonrefuge lakes where cisco/odoonibiins were predicted to have reduced probability of occurrence in the future. Jacobson et al. (2013) subsequently assessed the viability and costs of protecting cisco/odoonibiins populations across the state and recognised that cisco/odoonibiins conservation efforts in agricultural watersheds of the state may be challenging and could exceed necessary funding. Cisco/odoonibiins populations in nonrefuge lakes might represent scenarios where accepting future population responses to climate change remains the most feasible approach.

Similarly, despite the substantial effort put toward resistance to declining walleye/ogaa populations in Wisconsin, the number of walleye/ogaa fisheries in Wisconsin and the Upper Midwest supported by stocking has increased as natural recruitment in lakes has declined (Raabe et al., 2020). Natural resource agencies have limited capacity to provide fish for stocking. Therefore, agencies may increasingly have to make tough decisions as to when and where to stock walleye/ogaa. These decisions may include cessation of stocking on some lakes and not stocking every lake where natural recruitment has been lost (Hansen et al., 2015a, 2015b). Determining where agencies might accept the potential loss of walleye/ogaa



fisheries requires additional research on the costs and benefits of walleye/ogaa stocking at a statewide or regional scale and recognising that in some lakes survival of stocked fish will be low to nonexistent (Dassow et al., concurrent submission; Lawson et al., in press; Tingley et al., 2019b). While such an approach may differ from current approaches that manage fisheries at the individual-lake scale, in the future, it will be key to identify stocking strategies that maximise fishing opportunities at the landscape scale to best understand where walleye/ogaa stocking may not be viable and accept ecosystem change.

3.2 | Expansions of warmwater fishes

Thus far, expansions of warmwater species coincident with declines of cool and coldwater species have been discussed as a phenomenon met with intense resistance by state and tribal natural resource agencies in Wisconsin. However, many of the warmwater species that have or are projected to increase in distribution and abundance, particularly centrarchids (Kirk et al., 2022), support popular fisheries throughout North America, including in Wisconsin (Tingley et al., 2019a). The popularity of these species has led to a mixed management approach, where in many cases, few interventions have been implemented. Higher catch rates of these species would likely be amenable to many anglers so long as population size structure was also acceptable (Tingley et al., 2019a) and longer growing seasons could result in faster growth and improved size structure if compensatory density-dependence does not offset these potential angler desires (Hill & Magnuson, 1990). Greater capacity for growth may make these populations more resilient to harvest as fish require less time to reach harvestable length (Deriso, 1982). However, approaches for directing ecosystem change from historically coolwater to warmwater fisheries require support from communities of use, which will result in novel management challenges.

4 | DIRECTING ECOSYSTEM CHANGE

Of the three RAD strategies, *directing* ecosystem change is potentially the most difficult to effectively execute. A strategy of direction requires anticipating or projecting potentially novel ecosystem states in response to current and future stressors and implementing strategies to promote desired states or enhance properties or services supplied by that future state (Thompson et al., 2021). Fisheries management in Wisconsin has not attempted a true direct strategy to date. It is admittedly currently unclear what direct strategies may look like for some species, like walleye/ogaa and cisco/odonnibins, that may have either or both low ecological responsiveness to management action and low societal receptivity to change (Figure 2; Lynch et al., concurrent submission; but see Shultz et al., concurrent submission for examination of a possible example for walleye fisheries). However, some

examples of current management initiatives can provide insights into how direct strategies could be developed and implemented according to projected fish community transitions with climate change and shifting angler responses to those dynamic fishing opportunities (Figure 2).

4.1 | Panfish management

Panfish—a group of fishes termed for their similar length and desirability as table fare—include some species likely to benefit from climate change. In Wisconsin, black crappie/gidagagwadaashi *Pomoxis nigromaculatus* (Lesueur), yellow perch/asaawe, bluegill/agwadaashi, and pumpkinseed *Lepomis gibbosus* (Linnaeus) comprise the most popular and most harvested panfish species, representing 50–75% of all fish recreationally harvested from lakes each year (Embke et al., 2020). Of special importance are bluegill/agwadaashi and black crappie/gidagagwadaashi, which are increasing in popularity and are well-suited to take advantage of warming waters (Feiner et al., 2020b).

Shifting trends in panfish abundance and angler catch rates have coincided with at least two ostensible changes in angler perceptions and desires. Historically, panfish were largely managed with liberal bag limits for the dual reasons that anglers were interested in achieving high harvest rates and because panfish were thought to be resilient to high harvest and would generally respond positively (Rypel, 2015; Rypel et al., 2016). However, in recent years, angler attitudes toward panfish appear to be shifting from a harvest-orientation towards a more conservative mindset, potentially in response to long-term declines in panfish population size structure (Rypel et al., 2016) and a contemporary preference among anglers for catching fewer, larger fish than many small ones (Tingley et al., 2019a). For instance, anglers have become more supportive of restrictive regulations that may promote increases in fish length (Feiner et al., 2021; Hansen & Wolter, 2017) and to address concerns about overharvest driven by improvements in technology (Feiner et al., 2020a).

These changing attitudes offer agencies an opportunity to be proactive in developing new strategies to meet the evolving desires of panfish anglers, while potentially promoting new fishing opportunities as they arise on the landscape. In Wisconsin, this is most clearly demonstrated by a steady move toward more conservative regulations in response to stakeholder desires and increased research to better understand panfish fisheries as an important but underappreciated social-ecological system (Feiner et al., 2020b, 2021). The current statewide panfish regulation in Wisconsin is 25 fish per angler per day, but an increasing number of lakes have been moved to a 10 fish per day bag limit in response to stakeholder desires and petitions. These stricter regulations have been applied to lakes to rehabilitate fisheries dominated by small (but fast-growing) fish where life-history data suggest reduced harvest could increase the average fish length or to protect populations that currently provide fisheries that meet angler preferences (Jacobson, 2005; Rypel, 2015). At the same time, research documenting fish (Rypel, 2015)



and angler (Feiner et al., 2021) responses to changing regulations, angler effort and catch dynamics (Feiner et al., 2020b), the prevalence and effects of technology on ice angler efficiency (Feiner et al., 2020a), and the importance of panfish fisheries for shaping effort dynamics across the landscape (Tingley et al., 2019a) have informed ecologically-relevant regulations and changes in angler behavior. The WDNR is currently experimenting with novel regulations to further improve panfish size structure in about 100 lakes in the state (WDNR Panfish Team, 2015).

Gaining additional knowledge on the social importance and acceptability of panfish fisheries will be key in devising strategies to ensure anglers are able and willing to access potentially novel panfishing opportunities in the future fisheries landscape. Although the ecological management of expanding warmwater panfish populations represents an *accept* strategy (discussed above), developing policies, public outreach, education, and social strategies to promote these new fishing opportunities can help increase societal receptivity to change, enabling them to take better advantage of likely future conditions (Lynch et al., concurrent submission). As discussed below, the social dynamics of fisheries management are complex yet critically important, demanding interdisciplinary attention. Moreover, implementing new policies can be difficult. For example, the importance of walleye/ogaa fishing in Wisconsin among recreational anglers and tribes, and the research and management attention afforded the current struggles of many walleye populations (Embke et al., 2019; Rypel et al., 2018), may reflect a populace that could have difficulty transitioning away from walleye/ogaa. However, panfish, particularly bluegill, hold an underappreciated yet vitally important place in Wisconsin fisheries, and the development of quality bluegill fisheries may even help buffer lakes from the loss of walleye fisheries, suggesting some social willingness to shift among targeted species in Wisconsin anglers (Tingley et al., 2019a). Thus, the end result of panfish management policies could aim to provide a mosaic of fishing opportunities on the landscape, capable of sustaining a range of catch rates and fish sizes to meet angler desires (Hansen & Wolter, 2017).

5 | PERSPECTIVE ON CURRENT STRATEGIES: RESIST, RESIST, RESIST

As demonstrated above, Wisconsin fisheries management strategies have largely prioritised *resisting* the effects of climate change by attempting to maintain historical ecosystem services (Lynch et al., 2022; Schuurman et al., 2020). This has typically meant resisting declines of cool- and coldwater species like walleye/ogaa, yellow perch/asaawe, brook trout/maazhamegoons, and lake trout/namegos by attempting to reduce harvest through regulations and stocking (Table 1). These strategies may not be effective in the long-term, particularly when faced with climate and land-use influences that are often outside the agency control (Carpenter et al., 2017). Decision-makers may soon be forced to determine when tipping points have been reached that make resistance no longer feasible,

and shift toward actions to accept or direct ecosystem change (Lynch et al., 2021).

Recreational and subsistence fisheries are embedded in complex social-ecological systems, thus governance, public perception, and infrastructure may act to keep climate adaptation policies focused on resistance (Salgueiro-Otero & Ojea, 2020; Solomon et al., 2020), even when the effects of climate change are firmly outside of managerial control (Carpenter et al., 2017; Hansen et al., 2019). In Wisconsin, there are several hurdles facing state and tribal agencies and the public when attempting to incorporate accept or direct strategies. Social hurdles like the desire for traditional fisheries, which are culturally important for tribal users and reflective of baseline expectations for nontribal users, means that there is a strong preference for resist-oriented actions (Shultz et al., concurrent submission). Working with tribes, lake associations, angler groups, and stakeholders to realign user expectations with RAD decisions will likely require an interdisciplinary approach involving those with expertise in the social and ecological aspects of fisheries. Social scientists may be best able to facilitate discussion and guide the perceptions and expectations of the various stakeholders. Tribal communities, the first and current stewards in Wisconsin, have observed and learned from their environment over thousands of years, hereafter referred to using the common Western term traditional ecological knowledge (TEK; Chisholm Hatfield et al., 2018; Reid et al., 2021), but also known as indigenous and local knowledge (ILK) or indigenous experiential knowledge (IEK), all of which imperfectly capture this knowledge system. The Ojibwe themselves describe their way of knowing as *Anishinaabe-gikendaasowin*. Their relationship with the natural world is viewed through a lens of observation, deliberation, recognition, and adaptation (Shultz et al., concurrent submission; Tribal Adaptation Menu Team, 2019). Integrating tribal knowledge and perspectives will be vital in understanding how fisheries have changed over time, how tribal communities have adapted to changes in their relationships with fishes/giingoonyag, and how predicted changes in the environment might further influence these relationships (Shultz et al., concurrent submission). In tribal communities, engagement on a government-to-government basis (e.g., State of Wisconsin and Lac du Flambeau Tribe), including intergovernmental tribal agencies (e.g., GLIFWC), and additional listening sessions and consultations with tribal leaders, elders, and harvesters can ensure sharing of knowledge and perspective between tribal and nontribal entities. In nontribal communities, engaging with the general public may best be accomplished through localised stakeholder meetings and popular media channels commonly used by the various stakeholder groups, which is currently being done for natural resource management issues in Wisconsin (Solomon et al., 2020).

Entrenched agency culture represents another challenge for adjusting strategies. Structural hurdles like the history of heavy investment in fish hatchery infrastructure and the positive public perceptions that come with stocking make it difficult to reallocate resources from these types of resist strategies. For example, the WWI invested US\$8.2 million into state hatchery facilities, US\$2 million in municipal, tribal, and private aquaculture facilities,



and US\$1.3 million annually for operating costs starting in 2013 (WDNR, 2020). Developing accept or direct strategies, like changing regulations for warmwater species to promote those fisheries or implementing habitat projects that maintain ecosystem function, will have to overcome the investments in fish hatchery infrastructure, the loss of aquaculture jobs, and long-held assumptions that stocking can overcome ecosystem deficiencies to provide desirable fishing opportunities (Halverson, 2008; Sass et al., 2014, 2017). Considerations must also be made for legal and political hurdles, which might mandate that resist actions continue to occur for certain species (Lynch et al., 2021; US Department of the Interior, 1991). Furthermore, agencies may be held accountable by governments, stakeholders, and other leaders based on the success of specific species (e.g., walleye/ogaa), or have budgetary incentives or constraints limiting them to focus on single-species management (Wilson et al., 2018), further limiting the ability of agencies to flexibly adjust management outlooks or practices. Negotiations among tribal and state biologists to agree on RAD trajectories moving forward, by guiding public perceptions and expectations, solving structural hurdles, and satisfying legal and political constraints, will be crucial in aligning Wisconsin fisheries with the realities of intensifying climate influences on these valuable resources.

5.1 | Interactions and shifts in RAD components over time

Given the complexity of freshwater ecosystems, management actions that affect certain species rarely occur without corresponding consequences for species elsewhere in the local food web (Hansen et al., 2015a, 2015b), e.g., via trophic cascades (Ripple et al., 2016) or the loss or introduction of an ecosystem engineer (Emery-Butcher et al., 2020). One complication observed when applying the RAD framework to current management objectives is that many agency management plans are species-specific (e.g., goals are to rehabilitate walleye/ogaa). True RAD strategies operate on entire ecosystems (Lynch et al., 2021). Therefore, species-specific decisions in ecosystems may result in multiple RAD approaches being used simultaneously (e.g., stocking of a declining species [*Resist*], while liberalising harvest of increasing species [*Accept*]). Although often thought of as single-species management, the types of species-specific management objectives discussed here are often based on desires for certain types of ecological communities that provide specific desired outcomes. Aggregating management objectives into the RAD framework provides a path for decision-makers to account for social and ecological interactions when deciding how best to set and accomplish their resist, accept, or direct goals via ecosystem-based management (Magneess et al., 2022). Although these complexities may risk unintended consequences, well-studied systems can become catalysts for feedback loops of positive and desirable change.

Ecosystems and the institutions that manage them are not stationary through time. A capacity to adapt RAD decisions when needed allows managers to keep pace with shifting fish communities

and stakeholder attitudes, and to work toward institutional change while still making progress on management goals (Dassow et al., concurrent submission). In Wisconsin, eroding walleye/ogaa productivity and subsequent production overharvest presents a non-stationary system that requires updated management decisions to meet intensifying climate influences (Embke et al., 2019; Rypel et al., 2018; Tsehay et al., 2016). As fewer systems support resist actions aimed at preserving coolwater species, opportunities to improve fishing opportunities for warmwater species will emerge. For instance, Tingley et al. (2019a) documented the importance of bluegill/agwadaashi harvest opportunities as a key secondary characteristic influencing decision-making for Wisconsin walleye/ogaa anglers. As resisting walleye/ogaa declines becomes more difficult in some systems, transitioning to accept or direct strategies may allow managers the flexibility to improve bluegill/agwadaashi fishing opportunities and thus preserve a general harvest opportunity that anglers desire.

6 | SOCIO-ECOLOGICAL ISSUES FOR ADAPTING RAD STRATEGIES

Among the greatest sources of uncertainty in fisheries management are human decision-making and behavior (Fulton et al., 2011). The success of any RAD strategy depends on: (i) acceptability to human stakeholders of management actions and goals and (ii) consideration of whether the response of stakeholders to environmental and regulatory change can advance management goals or, conversely, lead to unexpected outcomes (Lynch et al., 2021). Recreational fisheries are often not self-regulating, even under stationary conditions (Hunt et al., 2011; Post et al., 2002; Wilson et al., 2020). As climate change shifts fish populations, anglers, subsistence fishers, and fishery managers, human responses to changes in fish communities will become even more important to understand and potentially predict and shape.

Anglers are remarkably consistent in their ability to maintain catch and harvest rates in the face of changing ecological conditions (Feiner et al., 2020b; Hestetune et al., 2020) and regulatory policies (Beardmore et al., 2011; Feiner et al., 2021; Powers & Anson, 2018). In the recreational and subsistence fisheries of Wisconsin, however, fish protein is not the only outcome that fishers desire. Among indigenous subsistence fishers, exercising their treaty rights to hunt, fish, and gather, which have historically been suppressed in the United States (Minnesota v. Mille Lacs Band of Chippewa Indians, 1999; Nesper, 2002; US Office of the President [Zachary Taylor], 1850), are culturally and spiritually important (Loew & Thannum, 2011; Nesper, 2002). In the case of recreational anglers, the challenge of catching fish, the experience in nature, and the wish to get away from everyday life are all additional motivations for fishing (Fедler & Ditton, 1994). Fishing effort that does not respond to changes in fish populations, either due to catch rate hyperstability or non-catch-related motivations, decouple feedbacks between catch rates and fish abundance, making overfishing more likely and the potential for fisheries population collapse more likely (Dassow et al., 2020; Erismann et al., 2011).

Because many recreational fisheries are not self-regulating, regulations are required to limit harvest. However, angler behavior in response to regulations is notoriously difficult to predict, as anglers may maintain or concentrate their effort (Beardmore et al., 2011; Powers & Anson, 2018), or switch species or sites (Beard et al., 2003; Beaudreau et al., 2018; Shultz et al., concurrent submission), to maintain their desired fishing opportunities in open access fisheries like those in Wisconsin. Regulations can therefore be ineffective or have unintended consequences (Miranda et al., 2017) – for example, redirecting fishing effort onto other species can initiate a regulatory “spiral” where increasingly restrictive regulations concentrate fishing effort through compensatory behavior (Abbott et al., 2018) or displace excessive fishing effort onto other species (Beaudreau et al., 2018). However, target substitution behavior can also be a positive outcome by presenting more opportunities for social-ecological adaptation because of harvest diversification (Beaudreau et al., 2019). Creel surveys suggest that harvest-oriented anglers in Wisconsin are already somewhat adjusting their target species in response to shifting species abundances (Embke et al., 2020). Although walleye/ogaa are among the most popular target species for recreational fishers in Wisconsin, the abundance of secondary species such as bass/ashigan and bluegill/agwadaashi still shapes decision-making and acceptability of fishing opportunities (Tingley et al., 2019a). Detecting these substitutions and proactively managing the affected populations, particularly across lake-rich landscapes such as Wisconsin, requires the increased scope of creel data or an improved understanding of social norms and motivations among anglers as these shifts are occurring. Less data exist on the behavior of Ojibwe subsistence fishers. However, their preferences, motivations, and, particularly, their willingness to substitute target species are likely different from those of recreational anglers given their much longer history of walleye/ogaa subsistence fishing in the region and the cultural importance of the activity (Nesper, 2002; US Department of the Interior, 1991).

Predicting angler behavior is extremely difficult because their responses to change are also representative of the societies in which they are embedded. Spurring behavioral change may be even more difficult. However, the influence of angling on fish communities makes understanding and developing strategies to adapt to the changing personal and social values driving angler behavior critical for future RAD fisheries management. The relatively recent growth of a catch-and-release ethic for muskellunge/maashkinoozhe and the black basses offers an example of the influences of changes in angler behavior, and a lesson in the dynamics driving such a change. Over the past few decades, Wisconsin muskellunge/maashkinoozhe and black bass recreational fisheries have shifted to almost entirely catch-and-release fisheries (Gaeta et al., 2013; Gilbert & Sass, 2016; Sass & Shaw, 2020). The voluntary cessation of the harvest of these species by anglers has coincided with increased densities, reduced lengths and weights, and potentially reduced trophy potential (Gilbert & Sass, 2016; Sass & Shaw, 2020). This marked change in angler behavior has been linked to previous management efforts to maintain high-quality largemouth bass/ashigan fisheries in the 1990s

through restrictive regulations (Hansen et al., 2015a, 2015b), and shifting popular opinion on the harvest of these species (Margenau & Petchenik, 2004). The relative speed at which a catch-and-release ethic was adopted in these fisheries suggests that shifts in social norms can be achieved through public outreach; however, changing social norms toward the harvest of these species may have outlasted their usefulness, and have now yielded a situation in which managers are limited in their ability to regulate the abundance of multiple species on inland lakes through fishing regulations (Miranda et al., 2017; Sass & Shaw, 2020). For instance, angler aversion to harvesting largemouth bass/ashigan may exacerbate the ongoing transition from percid-dominated to centrarchid-dominated lakes in Wisconsin (Hansen et al., 2017; Sullivan et al., 2020). Nonetheless, past changes in social norms suggest that angler behaviors are malleable with new information, but they also suggest that norms adopted as part of top-down regulatory changes, rather than as part of a participatory dialog, may result in entrenched behaviors (Sass & Shaw, 2020). Therefore, understanding socio-ecological feedback will be critical in accounting for the effects of social norms and public perceptions on RAD decision-making.

7 | CONCLUSIONS

The RAD framework offers a foundation to encourage managers to consider strategies other than *resistance* to ecological change, including methods to *direct* change toward new, but satisfactory, ecosystem states (Lynch et al., 2021). Upon review, current policies and preferences in Wisconsin have primarily focused on actions to *resist* climate change influences. The ability of these resistance tactics to maintain the status quo in the long-term is doubtful for some systems. Future strategies will likely require new efforts to *accept* or *direct* a new composition of fishing opportunities across the state. However, multispecies management presents a challenge for responding to climate change and in applying RAD principles, as fish winners and losers will likely arise depending on which species are best adapted to warming temperatures and altered hydrology. Promisingly, based on what is known about angler preferences and their willingness to adapt to new paradigms (through active switching or acceptance of new baselines), a shift in management strategy may not result in overly negative social or ecological outcomes, particularly when many of the species projected to maintain or gain relevance in new fisheries (brown trout/namegos, largemouth bass/ashigan, smallmouth bass/noosa'owesi *Micropterus dolomieu* (Lacépède), and centrarchid panfish) are highly valued for sport and food by much of the fishing population. An ultimate strategy that melds the RAD framework to adapt fisheries to climate change influences, while preparing tribal and recreational fishers to take advantage of new, actively managed opportunities, offers a guide for maintaining mutually beneficial fisheries over the long-term.

Any RAD action must have ecologically, socially, culturally, politically, and financially practical solutions, but what is practical is also driven by a combination of scientific evidence and public stakeholder



desires (Lynch et al., 2022; Thompson et al., 2021). No RAD action is passive—accepting a system transformation may not require physical management of the ecosystem but will require relationship building and information sharing with stakeholders and tribes. Participatory (or collaborative) adaptive management has been put forward as a strategy for managing complex social-ecological systems under often conflicting objectives and stakeholder groups (e.g., Berkes et al., 2008). Bringing stakeholders from outside of agency management and fisheries research into the management process brings valuable insights into local dynamics and the opportunity to potentially improve stakeholder satisfaction, regulatory compliance, and ecological knowledge (Berkes et al., 2008; Crandall et al., 2019; Solomon et al., 2020). In this framework for adaptive management, co-production of knowledge by collaborating stakeholders is used in an iterative cycle or “spiral” to develop system models, set management objectives, interpret monitoring data, and implement new management decisions (Fernández-Giménez et al., 2019; Lynch et al., 2022). A participatory adaptive management framework could be used in Wisconsin to continue the process of categorising and prioritising lakes for appropriate, customised management strategies. For example, similar lakes within the flexible fish-based lakes classifications system developed by Rypel et al. (2019) may need similar management strategies to maintain or improve fishing quality. Lakes are already prioritised for stocking according to their likelihood of supporting natural recruitment in the future (Hansen et al., 2015a, 2015b). Similar priorities could be developed to define acceptable harvest regulations as part of a “buffet-style” management approach as described by van Poorten and Camp (2019). Including TEK and drawing on tribal relationships with fishes/giingoonyag would ensure tribal cultural perspectives and needs inform any adaptive management process (Panci et al., 2018; Wyllie de Echeverria & Thornton, 2019). Co-production of relationships with fishes/giingoonyag (i.e., participatory design of management strategies) could be used to provide a variety of fishing opportunities to fishers with heterogeneous preferences while maintaining lakes with low-mercury walleye/ogaa populations for spearfishing based on GLIFWC consumption advisories (e.g., Moses, 2020). Bringing tribal and nontribal perspectives together in the development of management strategies could help in building mutual understanding and trust between groups that have a history of conflict over the relationship with, management of, and access to fisheries (Nesper, 2002). It must be acknowledged, however, that this knowledge co-production is not an end in itself or a management panacea, but the start of a long and involved process of social learning that requires substantial investments of funding and time.

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