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REVIEWS

# A bright spot analysis of inland recreational fisheries in the face of climate change: learning about adaptation from small successes

**Amanda L. Jeanson · A. J. Lynch · J. D. Thiem · W. M. Potts · T. Haapasalo · A. J. Danylchuk · T. D. Beard · R. Arlinghaus · L. M. Hunt · N. Young · S. J. Cooke**

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**Abstract** Inland recreational fisheries have social, economic, and ecological importance worldwide but these fisheries are increasingly challenged by the diverse effects of climate change. Coupled with other anthropogenic stressors, climate change has contributed to declines in freshwater biodiversity of greater severity than those observed across marine or terrestrial taxa. At a macro level, inland fisheries are experiencing declines. There are, however, a number of success stories, or 'bright spots,' in inland recreational fisheries management, where innovative approaches are leading to increases in social and ecological well-being in the face of climate change. Cases such as these are important sources of inspiration and learning about adaptation to climate and environmental change. In this article, we analyze 11 examples of such 'bright spots' drawn from multiple jurisdictions around the world from which we extracted lessons that might apply to fisheries management challenges beyond the region and context of each case. Collectively, these bright spots highlight adaptive initiatives that allow for recreational fisheries management to mitigate to stressors associated with current and future climate change. Examples identified

A 'positive future' for inland recreational fisheries in the face of current and future climatic change is possible! This work highlights potential strategies to adapt to current and future climate changes.

A. L. Jeanson (✉) · S. J. Cooke
Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada
e-mail: Amanda.l.jeanson@gmail.com

A. J. Lynch · T. D. Beard
U.S. Geological Survey (USGS), National Climate Adaptation Science Center, Reston, VA, USA

J. D. Thiem
Department of Primary Industries, Narrandera Fisheries Centre, Narrandera, NSW, Australia

W. M. Potts
Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa

T. Haapasalo
Department of Geographic and Historical Studies, University of Eastern Finland/Itä-Suomen yliopisto, Joensuu, Finland

A. J. Danylchuk
Department of Environmental Conservation, University of Massachusetts Amherst, Amherst, MA, USA

R. Arlinghaus
Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, and Integrative Fisheries Management and Integrative Research Institute for the Transformation of Human-Environmental Systems, Faculty of Life Sciences, Humboldt-Universität zu Berlin, Berlin, Germany

include community-based restoration projects, collaborative and adaptive approaches to short-term fisheries closures, transdisciplinary large-scale conservation projects, and conservation-minded efforts by individuals and communities. By highlighting examples of 'small wins' within inland recreational fisheries management, this review contributes to the idea that a 'positive future' for inland recreational fisheries in the face of climate change is possible and highlights potential strategies to adapt to current and future climate scenarios.

**Keywords** Anthropocene · Recreational fisheries · Social-ecological systems · Positive futures · Inland fisheries

## Introduction

Inland aquatic ecosystems (lakes, rivers, brackish and coastal wetlands, marshes and swamps, reservoirs, bogs, etc.; Janse et al. 2015) are facing severe habitat modification and biodiversity declines in the Anthropocene (a time in which humans are driving ecosystem changes; Lewis and Maslin, 2015; Reid et al. 2019), thereby causing social, economic, and ecological losses (Fike et al. 2007). Recreational fishing (e.g., the fishing for reasons other than obtaining sustenance or for profit from sales; FAO 2012) represents one sector that relies on inland waters. Engagement in recreational fishing is high, with an average of approximately 10% of the human population participating in the activity (Arlinghaus and Cooke 2009; Arlinghaus et al. 2015). It is estimated that up to 6.7% of the global population engage in inland recreational fishing and have a combined total catch of $\sim$ 11.6 million tonnes (FAO 2018).

High participation rates in recreational fishing can be linked to the social and psychological benefits gained from recreational fishing (e.g., connecting with nature, escape, relaxing, and socializing; Driver and Knopf 1976; Caltabiano 1994; Toth and Brown 1997; Freudenberg and Arlinghaus 2009; FAO 2018). The socio-psychological benefits accrued by anglers encourage them to incur expenses associated with fishing trips (e.g., travel, goods, and services), which in turn creates jobs and stimulates local and regional economies. In the United States of America (USA) alone, inland recreational fisheries generate over 31 billion USD annually in direct expenditures (Lynch et al. 2016). Globally, the recreational fishery sector within inland waters generates over 100 billion USD in revenues (Funge-Smith et al. 2018), often contributing in meaningful ways to livelihoods in smaller rural communities (Smith et al. 2005; Hoogendoorn 2014).

Current and projected climate scenarios threaten the integrity of ecosystems supporting inland recreational fisheries (Harrod et al. 2019), thus endangering the economic and social benefits resulting from this sector. Inland aquatic ecosystems have experienced biodiversity losses that are greater than those in terrestrial and marine environments (WWF 2016; Reid et al. 2019). General climate-driven threats to freshwater ecosystems include increased mean surface temperatures, losses in dissolved oxygen levels, changes in water availability and seasonality, increased eutrophication (Myers et al. 2017), greater frequencies of cold shock events (Szekeres et al. 2016), and changes in stratification patterns (King et al. 1999). Furthermore, changes in precipitation patterns (e.g., increases in drought frequency; Lennox et al. 2019) are shifting the distributions of fish species (Chu et al. 2005; Perry et al. 2005), leading to thermal niche contraction or expansion promoted through increased competition/predation from invaders (Mohseni et al. 2003; Pratchett et al. 2011).

Inland aquatic ecosystems supporting recreational fisheries are of significant conservation concern, as they must absorb fisheries-related stressors resulting from fisher interactions with fish (e.g., fishing mortality arising from harvest or incidental mortality associated with fishing injuries or stress encountered during catch-and-release fishing) and climate change driven stressors such as those listed above. For example, increased water temperatures and other climate-induced environmental changes can be physiologically challenging to species, especially when combined with exercise-induced stress resulting from

L. M. Hunt
Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources and Forestry, Thunder Bay, ON, Canada

N. Young
Department of Sociology and Anthropology, University of Ottawa, Ottawa, ON, Canada

catch-and-release fishing events (reviewed in Gale et al. 2011; Whitney et al. 2016). The conservation of fish populations used by recreational fisheries should therefore be a significant consideration for the fisheries management community to ensure the sustainability of the fisheries in the face of current and future stressors. Furthermore, anglers can influence the survival of angled fishes through the adaptation of conservation-driven behaviours. For example, when faced with high water temperatures in Western USA, anglers have altered behaviours to the benefit of angled fish species (Boyd et al. 2010).

The management of inland recreational fisheries in the Anthropocene should involve multi- and trans-disciplinary collaborations amongst social scientists and biologists, as well as relevant stakeholders (Arlinghaus et al. 2017). Human-related barriers (e.g., public and political will) are the greatest impediments to fisheries management success (Arlinghaus 2006; Hilborn 2007), demonstrating the importance of viewing fisheries as part of coupled social-ecological systems (Arlinghaus et al. 2017). Furthermore, inland recreational fisheries management must be forward-looking and adaptive to best mitigate current and future stressors associated with climate change (Pratchett et al. 2011; Szekeres et al. 2016; Lennox et al. 2019). To achieve a positive future for inland recreational fisheries, decision-makers can draw inspiration and learn from successful initiatives that create social-ecological bright spots (referred to by Bennett et al. 2016 as 'seeds towards a good Anthropocene') when looking for novel management strategies. These bright spots can serve as lessons for adaptive conservation measures to achieve sustainability in the face of current and future climate change scenarios.

Here, we outline a number of bright spots found within inland recreational fisheries. The included bright spots contain useful approaches to manage the impacts of climate change, and/or address other stressors (e.g., angling exploitation) in systems vulnerable to, or impacted by effects of climate change. The initiatives discussed here are all small-scale and local or regional in application. However, each one has demonstrated improvements in human well-being without negatively impacting or in some cases improving the environment, thus creating 'social-ecological bright spots' (Bennett et al. 2016). Geographically dispersed bright spots are analyzed together to illustrate tangible take-home lessons, and to share successful adaptive management tools to aid inland recreational fisheries management in the Anthropocene. By compiling successes in inland fisheries management at a global scale, this work gives fisheries managers the opportunity to adopt and build off of successes demonstrated in faraway fisheries to adaptively enhance their capacity to climate change.

## Methods

### Collection of bright spots

Examples of social-ecological bright spots were solicited via an email and social media call (e.g., via co-author twitter accounts) to researchers and fisheries managers around the globe who work with inland recreational fisheries. Emails and social media posts were written and shared by us authors to our contacts, thus reaching others in our professional networks. As our author list is comprised of experts in the field, soliciting through our own professional networks enabled us to successfully reach other experts working with inland recreational fisheries conservation and management and collect insightful bright spots. Inland fisheries researchers and managers study or manage fisheries facing climate change and anthropogenic stressors and are therefore well positioned to encounter examples of successful initiatives that have led to social and ecological successes in an inland fisheries context. We received a total of 14 bright spot suggestions by experts in recreational fisheries management world-wide. Of those 14, 11 submissions were from North America. A short-list of bright spot ideas was built from submissions that matched our criteria for a bright spot, as adopted from Bennett et al. (2016). Submissions had to be social-ecological, meaning that they demonstrate or show potential for social and ecological improvements. We define a successful social-ecological bright spot as: 1) promoting ecological sustainability (the ability of the ecosystem to withstand the needs of fishery users; Morelli 2011), and 2) promoting social and economic sustainability (the ability of the fishery to provide well-being and economic benefits to stakeholders; García-Llorente et al. 2006). The short list of bright spots was comprised of 11 submissions, all of which demonstrate these 'three pillars of sustainability' (social, economic and ecological sustainability; Purvis et al. 2019).

The co-author list is comprised in part of recreational fisheries experts who submitted selected bright spot cases for analysis. Some information regarding these bright spots originate from co-authors' personal experience. In some of the included bright spots, factual information was also sought via personal communications with key knowledge holders for a given fishery.

### Analysis

The framework for analyzing the included bright spots is based on criteria gleaned from two sources: Elmer et al.'s (2017) *Ten commandments for sustainable management for inland recreational fisheries management*, and Brownscombe et al.'s (2019) *The future of recreational fisheries: Advances in science, monitoring, management and practice* (see Table 1). Themes in Table 1 were agreed upon by co-authors as being central to included bright spots and echoed themes included in the two works mentioned above. Included bright spots were then analyzed to identify chosen themes in each. These themes were further dissected using examples pulled from our compilation of bright spots and resulting 'lessons learned' are shared below. Through this analysis, this paper provides tangible examples of fisheries management strategies and tools that can be adopted or scaled up to the benefit of other inland recreational fisheries around the globe as we continue to experience climate change-induced stressors, and other anthropogenic stressors.

## Bright spot cases

The bright spots are presented in no particular order, yet similar themed bright spots were placed near each other in the body of the text (see Fig. 1 for corresponding themes). The bright spots described below include examples of existing successes within inland fishery management, examples of management projects yielding ongoing initiatives within inland fishery management, and potential initiatives that are believed to bring successes in inland fisheries management. The rationale for success is included in the bright spot summaries.

### Temperature-based in-season closures in the Miramichi River (Canada)

The Miramichi River in New Brunswick, Canada, is essential nursery habitat for wild Atlantic salmon (*Salmo salar*) populations, which are highly valued amongst recreational anglers in the area. However, climate change induced high water temperatures have been linked to fatalities in this population of Atlantic salmon (Lund et al. 2002; Gallant et al. 2017). In response to resultant declines in the abundance of Atlantic salmon, the province of New Brunswick implemented adaptive temperature-based in-season fishery closures through collaboration with academics, Indigenous communities, recreational anglers, and other fishery stakeholders (Department of Fisheries and Oceans Canada 2019).

To protect Atlantic salmon under climate change and recreational angling-induced stressors, the province of New Brunswick implemented two exclusively catch-and-release Atlantic salmon fisheries in 1981 (Tufts et al. 2000). Fisheries remained open until water temperatures reached levels at which aggregations of salmon in cold-water refuges, mortalities, or low water levels were observed by Fisheries and Oceans Canada wardens. Decisions on closures were originally made on ad hoc bases after consultation with governmental and academic colleagues, as well as resource users. This allowed for input by those working directly in the system resulting in quick closures, but decisions were ultimately arbitrary. During an extreme thermal event in July 2010 in which temperatures in mainstem Miramichi River tributaries reached as high as 30.7° C during the day (Elvidge et al. 2017), and remained above 22° C at night over four days (Corey et al. 2017), high-density aggregations of juvenile salmon parr and mortalities of adults in deep-water pools were observed. This led to the current procedures for closures in the Miramichi River: fishery closures are now implemented after two consecutive 24-h periods in which water temperatures remain above 20° C, with a one-day lag period to allow news of the closure to be disseminated to resource users and commercial operations. Openings occur after two consecutive days in which water temperatures fall below 20° C (Fisheries and Oceans 2012a) to

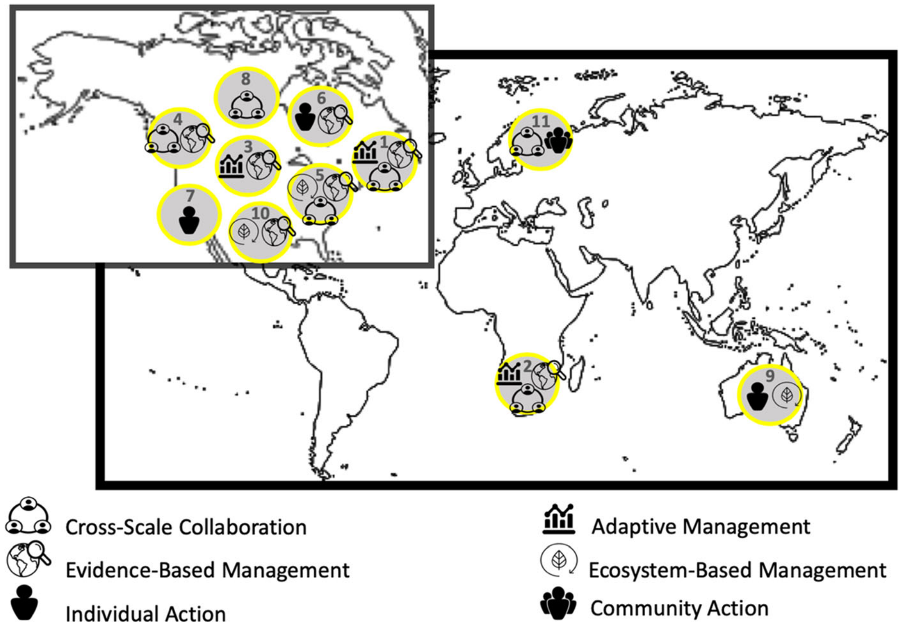


**Fig. 1** Map of bright spot locations categorized by theme (see Table 1). 1. Temperature-based in-season closures in the Miramichi River (Canada). 2. Water temperature and algal bloom-induced angling competition cancellations in South Africa. 3. Survival projections of cisco in warming waters: Minnesota lakes (USA). 4. Identifying climate shields for salmon conservation in Northern Rocky Mountains (USA). 5. The Lake Simcoe Watershed Climate Change Adaptation Strategy (LSCCAS; Canada). 6. Mitigating smallmouth bass range expansions (Canada). 7. Changes in angler behaviour in response to climate change (Western USA). 8. Harvest control of walleye using special walleye licensing in Alberta (Canada). 9. Resulting benefits of put-and-take fisheries formed by water infrastructure (Australia). 10. Eastern Brook Trout Joint Venture (USA). 11. Voluntary Longinoja Brook sea trout habitat restoration (Finland)

meet the physiological needs of Atlantic salmon, as they demonstrate decreases in metabolic performance and increases in mortality resulting from catch-and-release angling above this temperature (Dempson et al. 2002).

Success resulting from the Miramichi River temperature closures is defined by the ability to effectively remove angling stressors during periods in which fish cannot physiologically cope with both fishery and water temperature induced physiological stressors (promoting ecological sustainability). The current process in place for closures is the result of collaborative, and science-based management. Temperature-induced closures based on scientific knowledge of fish physiology and temperature trends such as those in the Miramichi River can result in adaptive and appropriate closures that benefit fish populations in question. By implementing species-specific maximum temperature thresholds for closures, the chances of fish populations in a system being subjected to lethal stressors from catch-and-release fishing is reduced, mitigating the high physiological cost of recuperating from fisheries stressors under high water temperatures. Using temperature-induced closures allows for the presence of a catch-and-release fishery to be present in the face of temperature concerns, allowing for continued economic and social sustainability of the fishery in the area whilst accounting for ecological sustainability of the system.

## Water temperature and algal bloom-induced angling competition cancellations in South Africa

The Rock and Surf Super Pro League (RASSPL) is a competitive catch and release South African shore-based marine angling league (competitions take place along the coast as well as inland in the Kei River). The league operates nationwide, with six franchises (each with eight different competition zones) situated in the cool-temperate and warm-temperate biogeographic regions of South Africa. Climate change and other anthropogenic stressors have led to water temperature spikes and concerning algal blooms in competition zones, threatening the survival of fish captured during

**Table 1** Take home messages for management divided by themes with examples pulled from bright spots

| Theme | Take-home message for management | Examples | Bright spots |
|---|---|---|---|
| Individual action | Management may recognize, foster and encourage the conservation-minded behaviours of individuals | Decisions by anglers to adopt conservation-minded behaviours can lead to changes in social norms, and ecological benefits for targeted fish species | 7 |
| | | Shifts in angling efforts from at risk populations can lead to ecological benefits for wild populations at risk in light of climate change | 6 & 9 |
| Community action | Management may recognize, foster and encourage conservation efforts from communities | Collective efforts by communities can lead to conservation successes without the involvement of management bodies | 11 |
| Cross-scale collaborations | Management may engage in cross-scale collaborations to increase available resources and knowledge, and yield management decisions supported by all stakeholders | Engagement with multi-stakeholders and governing bodies can provide increased resources and knowledge, favouring successful management decision-making | 4, 5, & 8 |
| | | Collective support for management decisions from stakeholders can positively influence the success of resulting management strategies | 1, 2, & 8 |
| Adaptive management | Management may include monitoring as part of conservation strategies in the face of climate change | Monitoring of temperature and other environmental parameters, fish population numbers, and habitat quality can allow for management to predict problematic scenarios and act quickly, thus minimizing the consequences of climate change-induced stressors | 1, 2, 3, 6, & 11 |
| Ecosystem-based management | Management may look to adopt ecosystem-based approaches to management | Restoring ecosystems can help re-establish fish populations supporting recreational fisheries | 5, 9, & 10 |
| Evidence-based management | Management may benefit from basing decision-making on evidence-based scientific findings | Scientific findings from environmental assessments and scientific experimentation can aid development of management strategies that best fit with the ecological needs of fishes and ecosystems | 1, 2, 3, 4, 5, & 10 |

competitions. In response, a research team from the Department of Ichthyology and Fisheries Science (DIFS) at Rhodes University partnered with RASSPL with the goal of finding strategies that allow for accurate and timely predictions of unfavourable water conditions on which to base decisions on cancellations, reallocations, or postponements of fishing competitions.

To protect targeted species under high water temperatures and concerning algal blooms, and to avoid having anglers travel and book reservations for postponed events, the collaborative research team is working towards practical solutions to best predict water conditions on competition days. To best predict water temperature, daily sea temperature based on in situ validated satellite observations (Moderate Resolution Imaging Spectroradiometer, i.e. MODIS terra; Reinart and Reinhold 2008) for each of the eight competitive angling zones for each franchise over the previous 10 years is compiled and the frequency of anomalous 'warm water events' is calculated based on knowledge of the thermal preference of the primary target species for each fishing zone, by month. Data are then used to identify high frequency warm water zones for each month where competitions should be avoided. Franchises are subsequently asked to adjust their competition schedules accordingly. Unlike water temperature, the presence of an algal bloom in a fishing zone can be accurately predicted based on information collected the previous day. For example, Hu et al. (2005) recommend the use of the near-real time MODIS fluorescence line height (FLH) data as a reliable satellite product for detecting red tides (harmful algal blooms) in coastal waters. The next steps for the research team will be to identify biologically relevant FLH values that could complement temperature indicators for the relocation or postponement of a competition (completion date by 2020).

Success resulting from the proposed strategy to be used by RASSPL is defined by the ability to effectively remove angling stressors during periods in which fish cannot physiologically cope with high water temperatures and algal bloom-induced stressors in a manner that will not greatly inconvenience anglers. The proposed strategy allows for timely and appropriate recommendations to relocate, or if all zones are negatively affected, postpone competitions. This strategy will allow for decisions to be made early enough as to not greatly inconvenience competition participants (anglers must book/pay for fishing-related travel and incur such expenses should a closure take place at the last minute; thus accounting for social sustainability of the fishery) and for survival of targeted fish species during periods of elevated water temperature and damaging algal blooms (thus promoting ecological sustainability). Oxygen concentrations and water temperatures are critical environmental parameters to post-release survival as hypoxia (like during a bloom of algal biomass; Hallegraeff 1993; Pick 2016) and high water temperatures (Dempson et al. 2002) have been found to impair fish recovery from catch-and-release events (Suski et al. 2006; Gale et al. 2013).

Survival projections of cisco in warming waters: Minnesota lakes (USA)

The USA state of Minnesota is known as the 'Land of 10,000 Lakes'. As the most prominent lentic forage fish in Minnesota, cisco (*Coregonus artedi*) live within some of these lakes (Jacobson et al. 2008), and play an important role in sustaining populations of lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), and northern pike (*Esox lucius*), that support socially and economically important recreational fisheries. Climate change has led to decreases in population numbers of cisco in Minnesota, at the trailing edge of their species range (Jacobson et al. 2012). Such declines threaten the success of recreational fisheries in the area as angling opportunities decrease with loss of cisco. In response to cisco population declines, the Minnesota Department of Natural Resources (MNDNR) used research to determine the most effective strategy for cisco management.

To protect populations vulnerable to climate change such as cisco, management can protect resilient habitat or, when that is no longer possible, engage in more intensive efforts to translocate them to suitable habitats (e.g., Winfield et al. 2012). Modeling the cisco thermal niche, Fang et al. (2012) identified 176 Minnesota lakes that are deep and clear enough to serve as refuge lakes, maintaining thermal habitat for cisco even with projected warming for Minnesota. The MNDNR then prioritized management action to proactively protect cisco habitat in these refuge lakes and surrounding forested watersheds. Furthermore, by protecting water quality and forest within these watersheds for cisco habitat and the recreational fisheries cisco support, the broader landscape also benefits from conservation efforts. Cisco habitat protection indirectly benefits the predatory fish feeding on cisco, which ultimately benefits recreational fisheries dependent on these predatory fishes in the area.

Success resulting from modeling cisco thermal niche is defined by the ability to proactively protect valuable habitat based on scientific findings in the face of ecosystem alterations induced by climate change. The strategy of using decision-support tools (e.g., science) to prioritize management investment allows one to optimize the use of limited resources for current recreational fishing goals and future ones. This approach opens doors to additional, often nontraditional, funding sources and builds a broad base of support with local, state, and federal governmental partners and non-governmental organizations. By considering the suite of available management options for current and future conditions, the MNDNR and others can maximize their conservation outcomes and ensure resiliency for cisco populations and predator populations (promoting ecological sustainability), and ultimately the recreational fisheries they support (promoting social and economic sustainability within the fishery).

## Identifying climate shields for salmon conservation in Northern Rocky Mountains (USA)

Recreational fisheries for primarily coldwater salmonids in the Northern Rocky Mountains of the USA are significant cultural and economic resources; in Montana, the recreational fishing industry contributes at least 1 billion USD annually to the economy (Outdoor Industry Association 2017). The dominant hypothesis for mobile species is that they relocate to maintain their optimal thermal habitat (e.g., the cisco in the case study above) when faced with climate change-induced stressors. Conventional wisdom suggests that coldwater fish in headwater systems, such as salmonids in the Northern Rocky Mountains, are particularly vulnerable to angling because they are often isolated and constrained in their ability to move to new habitat and are therefore, at high risk of extirpation.

To protect cold water salmonids in the Northern Rocky Mountains, a ‘climate shield’ approach in which cold waters are protected (by receiving a protected status eliminating any activity leading to the loss of such coldwater habitats) in order to preserve coldwater fauna and their ecosystem services (such as recreational fishing) is suggested. Isaak et al. (2016) show that thermal habitat in headwater streams is highly resilient to air temperature increases because of topographic controls. The ‘slow climate velocity’ of these systems suggests that they can serve as thermal refuge or ‘climate shield’ for salmonids and other coldwater aquatic species long after the surrounding landscape may have transformed (Isaak et al. 2015, 2016). In the case of coldwater salmonids in the Northern Rocky Mountains, it is suggested that cold refuges be identified by scientists, and protected to ensure the longevity of such populations, allowing for prosperous recreational fisheries in the area.

Success resulting from the ‘climate shield’ approach is defined by the ability to proactively identify (through scientific approaches) and protect climate shields under climate change thus aiding in the survival of salmonids (promoting ecological sustainability). The proposed strategy to protect coldwater salmonids can be less expensive and less intensive than other alternatives (e.g., translocation) to supporting recreational fishing for coldwater fish in the Northern Rocky Mountains in a changing climate (promoting social and economic sustainability). This simple concept can be used to strengthen existing collaborative approaches of natural resource agencies and recreational fishing stakeholders and foster new partnerships with other conservation interests in the area.

## The Lake Simcoe watershed climate change adaptation strategy (LSCCAS; Canada)

Lake Simcoe is home to lake whitefish (*Coregonus clupeaformis*), yellow perch (*Perca flavescens*), smallmouth bass (*Micropterus dolomieu*), and one of the most southern natural population of interior lake trout in Canada, making it a destination for anglers year-round. Lake Simcoe is the most-fished lake in Ontario with $\sim$ 1 million angler hours per year and is a particularly popular destination for ice fishing (Government of Ontario 2017). Climate change and other anthropogenic stressors onto Lake Simcoe have led to changes in aquatic life; emergence of invasive species; changes in water quality and quantity; and changes in aquatic fauna species; resulting in reduced opportunities for recreational activities such as angling (Government of Ontario 2017). In response, the Lake Simcoe Climate Change Adaptation Strategy (LSCCAS) was developed by the Ontario government.

To protect the Lake Simcoe watershed from climate change and other anthropogenic stressors, the LSCCAS looks to combat the negative implications of climate change onto the Lake Simcoe ecosystem, industries, and users (Government of Ontario 2017). The Government of Ontario has partnered with locals, Indigenous communities, municipal governments, industry, developers, and other identified stakeholders to build a comprehensive and expansive strategy for climate change management for the Lake Simcoe system. To protect valuable Lake Simcoe fisheries, the LSCCAS suggests deviating angler efforts from areas that are at a greater risk to climate change-driven stressors by promoting angling opportunities during different times of year or at different locations. Second, it suggests diverting angler efforts away from cold water species by promoting angling for more warmwater species that may actually fare better under climate change. Third, it suggests habitat restoration and protection projects to ensure quality habitat for Lake Simcoe fish species under climate change. Furthermore, the LSCCAS includes efforts to inform visitors about the impacts of climate change, and to provide suggestions on how visitors can do their part to negate stressors (Government of Ontario 2017).

Success resulting from the LSCCAS can be defined by its collaborative, trans-disciplinary, social-ecological approach to climate change management (Lemieux et al. 2014), thus ensuring and considering ecological, social and economic sustainability of the lake system. The inclusion of recreational fisheries management into an ecosystem-based, government-supported strategy can allow for resources and planning required to ensure the persistence of such fisheries in the face of climate change and other stressors. The LSCCAS strategy to fishery conservation includes collaborative efforts amongst stakeholders, education for users, and scientific findings on which to base management decision-making.

### Mitigating smallmouth bass range expansions (Canada)

Recreational angling contributes an average of 8.8 billion CDN to the Canadian economy, with smallmouth bass being a heavily targeted species (Brownscombe et al. 2014). As a consequence of changing climate, smallmouth bass in North America are predicted to expand their range into northern latitudes, and into habitats previously unavailable to them (Sharma et al. 2007; Sharma and Jackson 2008) with the help of facilitated introductions by the recreational fishing industry. Unfortunately, in Ontario, Canada alone, 25 000 populations of native cyprinid species may be lost as a result of direct predation by smallmouth bass in new locations (Jackson and Mandrak 2002). In response to these possible threats, it is suggested that introductions and invasions of smallmouth bass be mitigated by management following scientific risk assessments such as the one done in Kejimkujik National Park, Canada.

To protect native species and ecosystems throughout plausible smallmouth bass range expansions (both naturally occurring, and human-driven), it is suggested that invasive species risk assessments be conducted to assess potential threats to habitats with high invasive species vulnerability. Following the potential threat of smallmouth bass range expansion into Kejimkujik National Park in Nova Scotia, Canada, a risk assessment comprising of a computer-based analysis of habitat suitability, and literature reviews of potential management techniques were conducted. The assessment suggested devastating effects on the ecosystem following the presence of smallmouth bass, and so monitoring, and rapid post-detection action plans were put in place (Davis et al. 2016) to reduce the possibility of range expansion into the park.

Success resulting from risk assessments on potential invasive species such as smallmouth bass is defined by the ability to effectively predict environmental outcomes of such events, allowing for proactive management promoting ecological sustainability. Smallmouth bass expansion can be socially and economically beneficial to recreational fisheries across Canada, yet precaution must be taken to ensure that such expansions do not carry negative ecological implications. When properly managed, introductions as well as natural range expansions can result in fishing opportunities of preferred species without negative effects onto the ecosystem all while potentially removing angler pressure on other native populations fairing less well in the face of climate change and other anthropogenic stressors.

### Changes in angler behaviour in response to climate change (Western USA)

Recreational angling can be an important economic activity providing employment and other benefits (Ditton et al. 2002; Arlinghaus et al. 2007). To help protect targeted species and minimize the negative effects of catch and release angling on species threatened by climate change stressors, anglers can comply with regulations intended to reduce the lethal and sublethal effects of capture and handling on fish, and/or voluntarily modify their behavior to ensure impairment of targeted fish is minimized (Cooke et al. 2013).

In Western USA, increased water temperatures have elicited both voluntary- and regulation-mediated management of lotic systems supporting recreational fisheries (Boyd et al. 2010). For example, in the state of Montana, a drought fishing closure policy is now in place to 'limit the additive impact of angling mortality during stressful conditions created by drought'. In 2018, Colorado Parks and Wildlife initiated voluntary closures resulting from low river flow rates and associated high water temperatures. Similar voluntary requests by anglers targeting landlocked sockeye or kokanee salmon (*Oncorhynchus nerka*) were made in Wyoming in 2018, urging other anglers to stop fishing once they had harvested their limit to reduce temperature related mortality on fish being released. In Montana, so called 'hoot owl' closures have been instituted at warm temperatures. This involves daily closures that extend from 2:00 pm until midnight so as to protect fish from the hottest period of the day (see Mahoney 2016). Although this can be done formally with regulations (e.g., as in western Montana), it can also be achieved through voluntary means.

Success resulting from angler engagement in policy and/or voluntary pro-environmental changes in behaviour are defined by decreased angler-induced stressors onto targeted fishes (promoting ecological sustainability). Species facing stressors from recreational fishing and climate change are at greater risk, yet anglers can minimize these risks whilst continuing to socially benefit from the fishery by altering their behaviours on the water. Decisions to practice such behaviours is linked to knowledge on how capture and handling affects fish (Brownscombe et al. 2017) and also social norms within the recreational angling community (Danylchuk et al. 2018; Guckian et al. 2018). Although the effectiveness of respected mandatory closures and calls for voluntary action has yet to be directly quantified for recreationally targeted fish stocks, the precautionary nature of these potential changes in angler behavior can mitigate the compounding effect of climate change-induced stressors and those that result from catch and release fishing.

### Harvest control of walleye using special walleye licensing in Alberta (Canada)

Walleye are the most often caught species by Alberta anglers (Fisheries and Oceans 2012). Alberta is characterized by a low abundance of lakes with walleye (n = 177), and a high abundance of walleye anglers, resulting in troublesome efforts to manage walleye in an open-access recreational fishery (Sullivan 2003). In response to resulting reductions in walleye abundance in the mid-1990s, fisheries managers developed strategies to mitigate walleye declines, without removing social and economically valuable recreational walleye fisheries.

To protect walleye populations, the government of Alberta implemented very strict input-based regulations (used in open-access fisheries), which produced high catch rates for walleye at many lakes. However, such efforts were not well received by recreational anglers because management allowed for little opportunity for anglers to harvest walleye (Sullivan 2003). Continued angling dissatisfaction with strict input-based regulations led fisheries managers to implement a special harvest license (SHL) in 2006 in lakes where a sustainable surplus of walleye was available for harvest (Government of Alberta 2018). SHL directly controls harvest by requiring anglers to obtain and use a tag when harvesting walleye (Government of Alberta 2017). These tags are now allocated to anglers through lottery draws where anglers apply for tags for specific lakes and sizes of walleye. This lottery was based on the same principles for managing the hunting of big game wildlife species, including increased selection odds for anglers who applied but were not successful in the previous year's lottery. The SHL permits fisheries managers to move away from limiting access through lake closures and catch and release regulations. While no evaluation of angler satisfaction with the program exists, the demand for the program has increased faster than the availability of tags from 1815 applications in 2006 to 46,727 applications in 2018 (Government of Alberta 2019).

Success resulting from SHL permits is defined by resulting benefits onto walleye populations (promoting ecological sustainability), and potential increases in angler satisfaction with the fishery. Importantly, SHL internalizes the cost of overfishing by letting those anglers benefiting from harvest to pay (Arlinghaus et al. 2019). The use of SHL permits appears to have increased angler satisfaction as proxied by the increased number of applicants and is a successful method to manage population numbers of walleye in Alberta. By recognizing the desires of stakeholders (in this case, anglers), managers can develop strategies that fit not only the ecological needs of the fishery ecosystem, but rather the desires of fishery users, thus allowing for a socially, ecologically and economically sustainable fishery. In areas where climate change restricts the availability of walleye such as in Wisconsin where increased water temperatures favour largemouth bass (*Micropterus salmoides*) recruitment over walleye (Hansen et al. 2017), greater use of SHL may pay large dividends over open access management using annual licensing with unlimited individual landings.

### Resulting benefits of put-and-take fisheries formed by water infrastructure (Australia)

Human development along waterways has increased exponentially over the past few centuries, with the construction of large dams for water storage and hydropower substantially altering river systems globally (Dynesius and Nilsson 1994; Nilsson et al. 2005), including those in Australia (e.g. Thoms and Sheldon 2000). This in conjunction with other factors including climate change-induced stressors such as drought, has led to severe declines in several native Australian fish species, and damage to ecosystems, leaving many species at risk of extirpation or extinction (Crook et al. 2010; Koehn and Lintermans 2012). While the negative impacts of large dams are indisputable, put-and-take fisheries have been created in many of the resulting water reservoirs which provide an additional angling opportunity and help to reduce angling pressure on wild riverine populations (Howe et al. 2001).

Australia has an estimated 446 large dams (> 10 m in height), the majority of which are situated in Eastern Australia (Kingsford 2000). The presence of these dams has greatly altered (generally negatively) water-dependent biota (Walker and Thoms 1993; Gehrke and Harris 2001). The change from lotic to lentic habitats has also altered fish community structure and resulted in some species being unable to complete their lifecycles (e.g., Pelicice and Agostinho 2008). Other species, however, have been able to exploit and thrive in these altered habitats, in some instances to the benefit of recreational anglers. To aid efforts to protect native wild populations of targeted fishes, unique recreational fisheries with widespread stocking programs have been developed in habitats created by dams impounding Australian rivers (in which fish are stocked for the purpose of being caught and in some cases, kept by anglers; Hunt and Jones 2018).

Success resulting from put-and-take fisheries situated in catchment headwaters in Australia is defined by the potential to remove angling stress from wild at-risk populations, increasing ecological sustainability of at-risk systems. This assumption is made based on previous examples in which put-and-take fisheries have resulted in shifted angler efforts away from wild stocks (see Howe et al. 2001). Habitat created by impounding rivers has also resulted in opportunities for the creation of unique recreational fisheries, providing novel opportunities for anglers to fish recreationally and for subsistence, yielding health and wellbeing benefits for anglers (thus promoting social and economic sustainability; Eigenschenk et al. 2019; Korpela et al. 2014). For example, Forbes et al. (2016) identified that Murray cod (*Maccullochella peelii*), a popular recreational angling target, were not completing their life-cycle within an Australian impoundment and populations were reliant upon stocking. This information led to a regulation change whereby the species is able to be targeted, and harvested year round in this waterbody (Copeton Dam) during what would otherwise be a closed season to protect the species during the key breeding season (https://www.dpi.nsw.gov.au/fishing/closures/summary-fw-closures). Interestingly, growth rates are often found to be greater in fish living in the artificial habitats created by dams when compared to natural rivers and streams (Russell et al. 2015; Forbes et al. 2016). Although human-made water barriers pose major threats to aquatic ecosystems, using novel put-and-take fisheries resulting from existing dams with no likelihood for removal to alleviate angler efforts on stressed wild stocks can lead to positive environmental outcomes for wild fish.

### Eastern Brook Trout Joint Venture (USA)

Brook trout (*S. fontinalis*) have been traditionally distributed throughout the Eastern USA (Appalachians and eastward) from northern Georgia, along the spines of the Appalachians into northern Maine (MacCrimmon and Campbell 1969). Climate change-induced stressors threaten the survival of brook trout in the Eastern USA. In response, the Eastern Brook Trout Joint Venture (EBTJV) was developed as a data-centric approach for protecting, enhancing, and restoring brook trout throughout their eastern range under climate change-induced stressors (www.easternbrooktrout.org).

To respond to climate change-induced stressors on brook trout in their eastern range, the EBTJV conducted a range-wide assessment of the status of brook trout, showing that indeed decline had occurred (Hudy et al. 2008). Perhaps a more disconcerting finding was that in some parts of the range, very little was known about current distribution and population status making management very difficult (Hudy et al. 2008). A second assessment, built upon a more robust data set than the first assessment, was performed in 2013 that lead to the identification of patches of remaining brook trout habitat that present discrete populations (Whiteley et al. 2013). Data from these analyses have been used to both focus limited habitat funding around the primary goals of protection, enhancement, and restoration and has spurred management agencies to develop a more systematic approach to monitoring brook trout throughout the range.

Success resulting from EBTJV is defined by the ability to quantify the status of brook trout populations to best develop management strategies in the face of climate change. Primary mechanisms for conservation of brook trout in their eastern range are now numerical targets from the scientific assessment and will focus habitat efforts around reconnecting isolated patches of existing brook trout habitat. The science-based approach to identifying management priorities since 2006 has led to an overall total investment of approximately 18 million USD in conserving and restoring brook trout habitat. By efficiently distributing funds based on scientific knowledge, the potential for ecological benefits and sustainability of the fishery increases.

### Voluntary Longinoja Brook sea trout habitat restoration (Finland)

Sea trout (*Salmo trutta*) historically spawn naturally in several coastal rivers in Finland. In response to anthropogenic stressors, most natural stocks have been extirpated (Pellikka et al. 2015), decreasing the available sea trout that catch and release recreational anglers can target along Finland's coastline. Losses are specifically attributed to decreased available spawning habitat, loss of water quality (in part due to climate change), and overfishing (Koljonen et al. 2014; Erkinaro et al. 2011). Population numbers of fishes in rivers and brooks decreased significantly as a result of partial channelization, and poor water quality (Lähitieto 2017). For example; electrofishing efforts in 1998 yielded zero juvenile trout (LUKE 2018) in the Longinoja Brook.

In response to losses of sea trout in Finland, the Longinoja Brook restoration project was created to restore a sea trout population in the Longinoja Brook (an urban brook). Longinoja brook is a tributary to the Vantaa River in the Malmi suburb of Helsinki, Finland. Gravel, rocks, and woody debris were reintroduced to the riverbed, creating natural habitats for spawning and juvenile trout (Longinoja 2019a, b). In addition, juvenile trout from a Vantaa River population were stocked into Longinoja Brook in 1998, 2001, and 2002. The resulting onset of natural spawning events in Longinoja Brook was reported to be in 2001 and resulting naturally spawned juvenile trout in Longinoja Brook were documented in 2005 (Pellikka et al. 2015) at a density of 30 juvenile trout per 100 m of brook length (LUKE 2018). In 2012, the number of naturally spawned juvenile trout grew to 238 juveniles per 100 m of brook and in 2015, a record year, 343 naturally spawned juvenile trout were observed per 100 m of brook (LUKE 2018). Between 2001, when restoration efforts began, to 2019, the brook has slowly restored into suitable sea trout habitat through long-term co-operation amongst voluntarily involved locals. As a result of working directly with Longinoja Brook, people have demonstrated pro-environmental behaviours towards the brook. For instance, illegal fishing has not manifested into a problem even through the brook is accessible and located around populated areas, as locals are quick to sanction others trying to engage in illegal fishing practices (Maaseudun Tulevaisuus 2018).

Success resulting from the Longinoja Brook restoration project is defined by the ability of the community to independently restore a once native sea trout population by restoring habitat and introducing sea trout back into the ecosystem (thus promoting ecological sustainability). By fostering this population of sea trout, angling opportunities along Finland's coast are likely to increase, thus providing opportunities for social and economic gains through coastal recreational sea trout fisheries. The idea of protecting the brook lives on and has become a year-round public activity. Now, spawning sites, erosion of riparian areas and number of salmonid juveniles are annually monitored by locals and Luonnonvarakeskus (LUKE;

Natural Resources Institute Finland) allowing for more adaptive management of the brook. Longinoja Brook now holds the title as the most famous brook in Finland, and in 2019 it won the Biodiversity Award from the Finnish National Broadcaster (YLE 2019).

## Findings and discussion

While the bright spot cases described above are disparate, they exhibit common themes linked to successes in recreational fisheries management identified in past works (Elmer et al. 2017; Brownscombe et al. 2019). We can derive lessons from these cases for reforming inland fisheries management to enhance adaptive capacity to climate change. In the discussion below, we describe these themes extracted under the following titles (see Table 1): (a) individual actions, (b) community efforts, (c) cross-scale collaborations, (d) adaptive and ecosystem-based decision-making strategies, and finally, (e) evidence-based decision-making strategies. By defining and analyzing the cases above using a framework of existing themes linked to recreational fisheries management successes, we hope to provide insight for fisheries management to aid in the implementation of successful management strategies. By embracing the lessons presented here, we can reform inland fisheries management practices, making them more adaptive and enabling management strategies that better mitigate climate change and other anthropogenic stressors.

### Individual actions

Efforts by individuals can have long lasting, positive environmental impacts, and can greatly increase the likelihood of success of management policies and strategies for recreational inland fisheries facing climate change-induced stressors (Bennett et al. 2018; Chapmin III et al. 2015). In the bright spots presented above, the actions of individuals often had a direct impact on the ecosystem in which they fished. Individual anglers on the water positively impact outcomes by setting social norms through the promotion of best practices (e.g., in relation to catch-and-release), and by educating and sanctioning others to engage in conservation-minded behaviour out on the water (Stensland et al. 2013). In the 'Changes in angler behaviour in response to climate change (Western USA)' bright spot, anglers voluntarily advocated against continued fishing once catch limits were reached, to ensure that fish did not experience excess handling stress as a result of catch and release fishing. By creating social norms on the water through angler to angler sanctioning against said behaviours, and through the promotion of alternative behaviours, individual anglers can minimize the effects of angling on fish physiology.

Individual anglers can also make significant contributions to the sustainability of inland recreational fisheries by engaging in ecologically beneficial fishing practices. For example, in the bright spots 'Mitigating smallmouth bass range expansions (Canada)' and 'Resulting benefits of put-and-take fisheries formed by water infrastructure (Australia)', anglers altered their efforts to focus on non-threatened populations of fishes, thus decreasing pressure on species at risk under current or future climate change scenarios. The decision made by anglers to shift angling efforts away from at risk populations is not always a conscious pro-ecological act, yet it benefits previously targeted, at risk native populations of fishes just the same. Consultation with resource users may be beneficial to natural resource management, as users often have creative solutions to issues that potentially limit fishing opportunities, and monitoring their actions may capture potential bright spots.

### Community efforts

Community efforts can lead to inland fisheries success by raising the visibility of conservation concerns to higher levels of management, thus accruing resources for conservation. Also, community engagement in conservation efforts can mobilize long-term volunteer labour that can inspire long-term commitment to conservation activities. These activities can help to sustain conservation efforts whilst climate change continues to alter landscapes and ecosystems. Furthermore, support by resource user communities can also improve the likelihood of successful implementation of policies and management strategies.

The resulting successes of the bright spot 'Voluntary Longinoja Brook sea trout habitat restoration (Finland)' demonstrates that achievements can be obtained through long-term voluntary-based community work. The restoration of Longinoja Brook is a prime example of the power of the general public's interest in local ecosystems, and the potential of collective stewardship. Collectives of individuals can identify a concern, rally for support for a cause, and engage in conservation efforts (Granek et al. 2008). The Longinoja Brook project began out of the desire of local anglers and community members to once again enjoy a brook that supports sea trout. A small community of actors was able to get others involved, including the Natural Resources Institute Finland (LUKE 2018), expanding community involvement to include a government organization, which provided additional support and resources.

Support from angling communities can also greatly increase the likelihood of success following novel policies or management strategies implemented in response to climate change-induced declines in fish populations supporting fisheries. For example, the 'Harvest control of walleye using special walleye licensing in Alberta (Canada)' bright spot demonstrates the importance of the accordance between the desires of fishery user communities and implemented policies. As walleye anglers in Alberta value the ability to harvest, angler effort following implemented fishing regulations imposing *no harvest* was extremely low, resulting in social and economic losses for the fishery. When regulations were altered to allow for sustainable and regulated levels of harvest, angler effort increased suggesting that social and economic benefits of the walleye fishery also increased. Management may therefore look to recognize, foster and encourage conservation efforts from communities.

## Cross-scale collaborations

Inland recreational fisheries often cross human-made boundaries such as political jurisdictions and are often comprised of numerous stakeholders with differing agendas, making inland fisheries co-management complex (Yandle 2003). Humans, however, are the primary determinants of management successes of inland fisheries (Arlinghaus 2006), and so incorporating the opinions and suggestions from all stakeholders is needed. This incorporation includes stakeholders that are often neglected from fisheries management decision-making in the face of climate change, such as anglers or Indigenous communities (Ranger et al. 2016).

In the bright spots 'The Lake Simcoe Watershed Climate Change Adaptation Strategy (LSCCAS; Canada)', 'Identifying climate shields for salmon conservation in Northern Rocky Mountains (USA)', and 'Temperature-based in-season closures in the Miramichi River (Canada)' co-management occurs amongst varying levels of government, stakeholders and resource users, including anglers, Indigenous communities, and NGOs. In these cases, decision-making followed engagement with stakeholders, allowing for management decision-making to align with the desires and needs of all stakeholders.

Continued, long-term engagement with stakeholders is prominent amongst many bright spots. The bright spot 'Voluntary Longinoja Brook sea trout habitat restoration (Finland)' still receives volunteer efforts from the community, and continued monitoring efforts from LUKE, allowing for continued success, regardless of potentially changing threats to the system. Bright spots 'Temperature-based in-season closures in the Miramichi River (Canada)' and 'Water temperature and algal bloom-induced angling competition cancellations in South Africa' continuously rely on successful channels of communication between scientists, fishery managers, and resource users to successfully implement adaptive and appropriate fishery closures. Furthermore, the bright spot 'Harvest control of walleye using special walleye licensing in Alberta (Canada)' relies on continuous communication amongst anglers and management to ensure that management strategies match the needs and wants of anglers, and the ecological needs of the targeted fishes under current and future climate change, allowing for a sustainable fishery (defined here as a fishery that can persist and mitigate the social-ecological stressors in today and tomorrow's world).

## Ecosystem-based management

Inland recreational fisheries are not found in isolation, as they rely on ecosystems in which they are established. To achieve sustainable fisheries, ecosystems must also thrive, and so an ecosystem-based approach to inland recreational fishery management may help (Beard et al. 2011; Pajak 2011). Many of the bright spots described herein include consideration for the ecosystems in which fisheries are situated. For example, the central focus of the bright spot 'Voluntary Longinoja Brook sea trout habitat restoration (Finland)' was to restore a brook ecosystem to allow for the return of sea trout. In the bright spot 'Eastern

Brook Trout Joint Venture (USA)', evidence-based approaches were implemented to not only protect fish populations, but also to ensure habitat restoration and enhancement. Furthermore, the 'The Lake Simcoe Watershed Climate Change Adaptation Strategy (LSCCAS; Canada)' bright spot acknowledges Lake Simcoe as a social-ecological system and looks to incorporate the needs of the ecosystem as well as the needs of resource users and industries into watershed management.

### Adaptive management

Management of inland recreational fisheries must be adaptive as climate change continues to alter aquatic ecosystems (Arlinghaus et al. 2017). Monitoring ecosystems to quickly identify problematic scenarios and troubling trends can greatly benefit conservation efforts (Arlinghaus et al. 2019; Brownscombe et al. 2019; Pajak 2011). Furthermore, monitoring allows managers to make projections that can aid in the building of management strategies that can address future stressors. With current and future climatic changes predicted to greatly alter the composition and conditions of inland recreational fisheries (Pratchett et al. 2011; Szekeres et al. 2016; Lennox et al. 2019), the ability to predict and mitigate for future stressors is of importance for fisheries management (Brownscombe et al. 2019). For example, in the 'Survival projections of cisco in warming waters: Minnesota lakes (USA)' bright spot, water temperature monitoring was used to model thermal niches and future water temperature conditions to allow for management to adapt to future stressors and to better focus efforts. In the bright spots 'Temperature-based in-season closures in the Miramichi River (Canada)' and 'Water temperature and algal bloom-induced angling competition cancellations in South Africa', monitoring of water temperatures allowed for effective fisheries closures as periods of dangerously high water temperature are predicted and identified. Furthermore, in the bright spot 'Voluntary Longinoja Brook sea trout habitat restoration (Finland)', continuous monitoring of population numbers by LUKE allowed for forward looking adaptive management of newly introduced sea trout.

### Evidence-based decision-making

The importance of measuring ecosystem resilience to climate change-induced stressors to inform decision-making is prominent amongst the described cases. For example, bright spots 'Temperature-based in-season closures in the Miramichi River (Canada)' and 'Water temperature and algal bloom-induced angling competition cancellations in South Africa' represent management decisions and policies that have reduced human-induced stressors to the ecosystem when it is already facing environmental stressors (e.g., high water temperature) through temperature closures designed around the physiological needs of angled fishes.

Furthermore, all bright spots presented above are in part the results of adaptive conservation decision-making based on sound scientific findings. This is not surprising, as it is known that reliable and applicable scientific findings increase the efficacy of inland fisheries management (Cooke et al. 2017). In the bright spot 'Eastern Brook Trout Joint Venture (USA)' for example, scientific evidence was used to guide protection, enhancement and restoration efforts for trout habitat in the USA. Furthermore, in the bright spot 'Identifying climate shields for salmon conservation in Northern Rocky Mountains (USA)', scientific evidence was used to demonstrate the importance of climate shields for salmon conservation, promoting efforts to identify and protect climate shields in salmon habitat. And in the bright spot 'Resulting benefits of put-and-take fisheries formed by water infrastructure (Australia)', research on stocking effectiveness identified a lack of evidence of a self-sustaining wild population of Murray cod which was used as the basis to lift a seasonal closure on fishing regulations aimed to protect a key spawning period for a recreational angling species whilst maintaining closed seasons for wild fisheries.

## Final thoughts for management

Although climate change and other anthropogenic stressors continue to threaten and change inland aquatic ecosystems supporting inland recreational fisheries, successes in management are ever present. This work presents bright spots at a global scale from which managers can adopt strategies at various actor levels. As climate change continues to alter fishing opportunities, there will undoubtedly be more pressure and need for all involved parties to develop creative solutions for recreational fisheries management in the Anthropocene. What is clear is that actions needed must span individuals and institutions if we are to achieve responsible and sustainable recreational fisheries in the Anthropocene (Cooke et al. In Press).

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