Biological Conservation 322 (2026) 112037

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Perspective

Embracing wicked problems thinking will advance conservation science and practice

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A R T I C L E   I N F O

Keywords:
Collective action research
Conservation science
Environmental problems
Wicked conservation problems

A B S T R A C T

Wicked problems thinking has been used to describe problems related to food security and health care, but it is often underused or misused to describe and investigate conservation problems. In this paper, we define wicked conservation problems as conservation problems that involve the following: (1) non-human, more than human, and human actors; (2) conflicting values among actors; (3) uncertainty that is non-reducible; (4) an extended timeline with no set end; (5) a need for satisficing decisions agreed among most actors; (6) inability to isolate the nature of the problem; (7) no test of success; and (8) every wicked conservation problem can be considered a symptom of another problem. We explore three case studies of conservation science problems, two of which have not been described previously in the literature as wicked problems. Using our definition of a wicked conservation problem, we provide evidence that each case study meets the criteria of a wicked conservation problem. To better support conservation scientists in studying wicked conservation problems, we provide several recommendations to facilitate more effective research: (1) where appropriate, accept a conservation problem as a wicked conservation problem; (2) take collective action; (3) set and manage expectations; and (4) reassess the wicked conservation problem as it evolves. We hope that this paper will be used by conservation scientists to conduct and facilitate more context-appropriate research on wicked conservation problems.

1. Introduction

Rapid declines in biodiversity (Naggs, 2017; Díaz et al., 2019), loss of habitat quantity and quality (Hanski et al., 2005), and alterations of ecosystem functioning (Tylianakis et al., 2008; Valiente-Banuet et al., 2015) are all common outcomes of human activities (Vitousek et al., 1997). To address these issues, conservation actions such as the creation of protected areas (Edgar et al., 2014; Giakoumi et al., 2018), ecosystem restoration (Davies, 2011; Wortley et al., 2013), species reintroductions (Maschinski and Albrecht, 2017; Harding et al., 2025), and invasive species control programs (Malpica-Cruz et al., 2017; Conti et al., 2021) have been used. Although there are many documented, successful conservation actions (Fleming and Fleming, 2009; Langhammer et al., 2024), there have also been many failures such as the extinction of Javan rhinoceros [*Rhinoceros sondaicus*] in Vietnam (Brook et al., 2014) and the social failure (e.g., increasing conflict among actors that is poorly managed) of marine protected areas in southeast Asia (Christie, 2004). Despite these failures and the uncertainty of success in conservation, protecting biodiversity remains important due to the social, cultural, economic, and intrinsic value that biodiversity provides (Soulé, 1985; Cooney and Dickson, 2005). Conservation science is known as a crisis discipline due to the uncertainty

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https://doi.org/10.1016/j.biocon.2026.112037
Received 5 February 2026; Received in revised form 25 July 2026; Accepted 30 July 2026
Available online 6 August 2026

and need to take immediate action at times (Soulé, 1985; Chan, 2008). Conservation practitioners are often tasked with making decisions to protect biodiversity within short timelines and without access to all required or opposing knowledges (Soulé, 1985; McCarthy, 2014; Henderson, 2018). Given the complexity of conservation issues, they have often been referred to as wicked problems (Game et al., 2014; Szydlowski, 2024), but wicked problems are more than just complex problems. For example, the decline of songbirds and raptors in North America caused by dichlorodiphenyltrichloroethane (DDT) following World War II (Carson, 1962) was a complex conservation problem not a wicked conservation problem. It was a complex problem because there was one ultimate agreeable solution among actors[2] that recovered the populations (Grier, 1982; Jaga and Dharmani, 2003). To better support conservation practitioners, knowledge producers must understand exactly what wicked conservation problems are, how wicked problems are studied, and how to generate knowledge that is helpful to decision-makers facing wicked conservation problems.

In this paper, we provide guidance for conservation scientists to facilitate and encourage more context-appropriate and, therefore, more impactful and actionable research on wicked conservation problems. Our objectives are (1) to define and provide context-driven understanding of wicked conservation problems to researchers, and (2) to facilitate more impactful research on conservation problems through wicked conservation problems thinking. To do this, we contextualize wicked conservation problems through a brief historical overview of the wicked problems literature. We then provide a definition of wicked conservation problems and use global case studies to provide real-world examples. Finally, we present a framework for conducting research on wicked conservation problems. We submit that embracing wicked problems thinking will advance conservation science and practice.

2. Wicked problems

To our knowledge, the concept of 'wicked problems' was introduced in the academic literature by Churchman (1967) following a presentation by Dr. Horst W. J. Rittel at the University of California, where the idea was first presented. In their editorial, Churchman defined wicked problems as ethical challenges for planners and systems analysts, calling them to consider the broader consequences of their solutions, with moral underpinnings that are not easily solved. Rittel and Webber (1973) coined the term 'wicked problem' and provided a formal definition that included ten distinguishing features: (1) no definitive formulation, (2) no stopping rules, (3) no true or false solutions, (4) no ultimate tests of solutions, (5) no opportunities for trial and error, (6) no set number of potential solutions, (7) essential uniqueness, (8) connection to other wicked problems, (9) discrepancies (often numerous), and (10) consequences for refuted hypotheses. Ultimately, wicked problems are those that have no simple solution—they are 'untame' problems that involve multiple actors with competing interests and values, multiple points of uncertainty, and no time limit on solutions (Head, 2022). In fact, wicked problems may never be solved—only managed more or less effectively over time (Zellner and Campbell, 2015). These ideas have been accepted and adopted in various disciplines, including political and environmental sciences, and are gaining greater recognition in research at large (Lönngren and Van Poeck, 2021; Hou et al., 2022).

Modern environmental problems like ocean warming, increasing frequency of extreme weather events, deforestation, overfishing, habitat loss, invasive species, mining impacts, and chemical pollution exemplify wicked problems (Thompson and Whyte, 2012; Head, 2014; Kirschke et al., 2018). Although their characteristics are not new (Grint, 2022), the consequences of poorly studied and managed wicked problems are increasingly severe. Traditional environmental management approaches often assume that optimal solutions can be reached through rational, scientific methods alone (Balint et al., 2011). However, in contexts defined by high uncertainty and conflicting values among actors, such assumptions are inadequate. This explains why rational, scientific approaches have often failed to resolve or substantially advance complex conservation issues, and why sustainability remains absent in many socio-ecological systems (Ostrom, 2009).

Although the concept of wicked problems has been explored in environmental and conservation research, there remains a need for overarching principles and frameworks that specifically guide researchers to conduct impactful research on conservation problems with 'wicked' characteristics. Existing definitions, which are often rooted in broader environmental and policy contexts, highlight features such as complexity, uncertainty, and contested values (Game et al., 2014). However, previous literature often inadequately addresses the priorities of conservation issues, which involve socio-ecological systems with complex (and beyond complex[3]) cultural, political, and ecological dimensions (Reed et al., 2019). Conservation science not only involves scientific uncertainty and actor conflict, but also requires navigating trade-offs among competing values, long-term ecological goals, immediate human needs, and non-human and more-than-human[4] actors (McShane et al., 2011; see Mason et al., 2018 for holistic management-based approaches to wicked conservation problems). As a crisis discipline (Soulé, 1985; Chan, 2008), conservation science necessitates an adaptive framework to guide researchers looking to conduct impactful research on conservation problems. However, current definitions of wicked problems (Rittel and Webber, 1973; Alford and Head, 2017) either lack the nuance needed to fully capture the scope and implications of wickedness in conservation science or use criteria that are too rigid to capture the wickedness exemplified in conservation problems. Additionally, researchers may be unaware of these past definitions or fail to converge on a single definition to guide their research on wicked conservation problems. Better approaches to researching and understanding wicked conservation problems are needed to meet the growing needs of conservation issues, especially among researchers who aim to support policymakers, managers, and other decision-makers in conservation.

3. On wicked conservation problems

We accept and recognize past definitions of wicked problems theory (dating back to Rittel and Webber, 1973) but believe our adapted understanding and definition of wicked conservation problems will help frame wicked problems thinking more succinctly to conservation science in support of conservation practice. We also accept previous definitions of wicked conservation problems (see DeFries and Nagendra, 2017;

[2] Actors include and are not limited to conservation groups, government organizations, Indigenous communities, Indigenous rightsholders, non-Indigenous communities, industries, shareholders, species, and ecosystems.

[3] Complex problems are those that do not have a straight-forward solution, often involving continuous adaptation and context-specific efforts. Beyond complex problems are those characterized by high levels of uncertainty and divergent values, where there is no single, clear solution or pathway to solve the problem, which may not even be solvable due to its continuous evolution and involvement of 'invisible' relationships. For further understandings of complex and beyond complex problems, see Ofori-Dankwa and Julian (2001) and Alford et al. (2025).

[4] The term "more-than-human" seeks to challenge past understandings of human-environment relationships which tended to be based on anthropocentrism. The more-than-human recognized the interconnected reality of all beings, this includes not only living beings, such as animals, but also "non-living" beings such as rivers, rocks, or ecosystems. This understanding of relationality is grounded in Indigenous knowledges globally, where humans have kinship-based relationships with non-humans, where animals, plants, water, and everything in the world (which has now expanded into human-built environments and technology) has agency and needs to be treated in reciprocal and relational ways. We encourage readers to explore these topics further, please see: Abram, 1996; Johnson and Larsen, 2018; Viaene, 2021; Parsons, 2023.

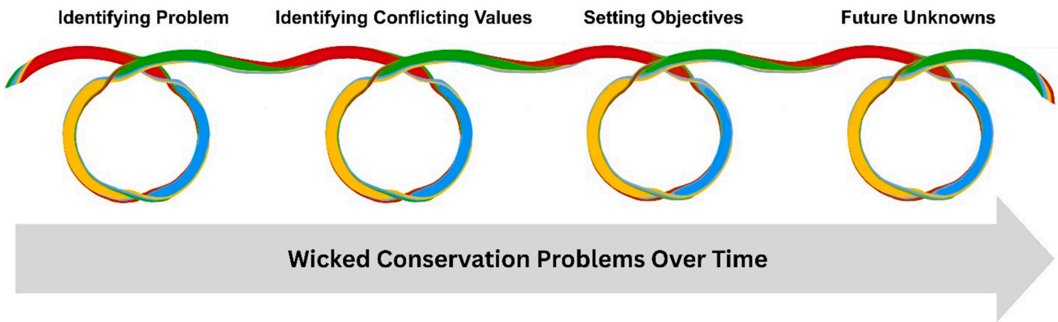

Fig. 1. Wicked Conservation Problems Spiral. This spiral provides a visual depiction of the evolving nature of a wicked conservation problem over time. Each loop is composed of interwoven segments that have their own dominant periods. This represents the multifaceted nature of the problem. Each loop represents a new arising issue within the wicked conservation problem, with their own evolving goals and side effects, requiring constant reassessment.

Mason et al., 2018) and have adapted ideas presented in those papers to provide a specific, corresponding framework for modern conservation practices. We define wicked conservation problems as problems that entail (1) non-human, more-than-human, and human actors; (2) conflicting values among actors; (3) uncertainty that is non-reducible; (4) an extended timeline with no set end; (5) a need for satisficing[5] decisions that are agreed upon by most actors; (6) inability to isolate the nature of the problem; (7) no test of success; and (8) every wicked conservation problem can be considered a symptom of another problem. As opposed to classic definitions of wicked problems, wicked conservation problems are confounded by an uncertain amount of time and various human and non-human actors. For example, in the context of imperiled species, it is difficult to know when a species of concern may go extinct, but solutions do not have a definite time in which they will certainly work. We acknowledge that these characteristics will not necessarily be expressed simultaneously or to the same degree within every wicked conservation problem. As noted in previous wicked problems literature (Alford and Head, 2017), a problem may be considered 'wicked' when most (not all) criteria are met. We also believe it is important to describe conservation problems as wicked conservation problems only when this description is accurate and warranted. If conservation problems that are complex (but not wicked) are incorrectly described as wicked conservation problems, actors may unnecessarily settle for satisficing decisions when optimal solutions are available (Noordegraaf et al., 2019; Termeer et al., 2019).

4. The wicked conservation spiral

Here, we introduce the *Wicked Conservation Problems Spiral* (Fig. 1) as a conceptual tool to describe conservation research through theories of wicked problems and through our definition of a wicked conservation problem. Wicked conservation problems have extended timelines and tend to be cyclical in nature; attempts to address one issue often generate new challenges that require further investigation, mainly due to their lack of a set endpoint. For example, in conservation science, even when specific threats are addressed (such as protection measures for a species at risk), the initial solution may only be temporary or prove ineffective, or the initial threat (such as an invasive species) might remain (Gordon et al., 2024). In our *Wicked Conservation Problems Spiral*, each loop represents a specific question or problem that actors aim to address within a broader conservation context. Our definition of wicked conservation problems also recognizes that actors are integral to the research questions and to inform more effective management. We represent these actors—human, non-human, and more-than-human—as braided strands that form the *Wicked Conservation Problems Spiral* itself. This structure seeks to acknowledge non-Western knowledge systems, particularly the reciprocal land-human relationships expressed in Indigenous knowledge systems and other works (e.g. Leopold, 1949). These concepts are effectively explained by Indigenous knowledge holders such as Dr. Kimmerer, a Citizen of the Potawatomi Nation (see Kimmerer, 2013), and in works on Two-Eyed Seeing approaches, as outlined by Mi'kmaw Elder Albert Marshall, where Western and Indigenous knowledge are used alongside one another through co-learning, co-evolution, and co-management (Haverkort and Rist, 2004; Bartlett et al., 2012; Reid et al., 2021).

Using our *Wicked Conservation Problems Spiral*, we present a hypothetical yet common scenario of a wicked conservation problem. In this scenario, a species that is ecologically, economically, and culturally significant is in rapid decline due to several stressors (e.g., habitat loss, overharvest, climate change, invasive species). This decline has raised concern for numerous actors, such as conservation groups, government organizations, Indigenous communities and rightsholders, non-Indigenous communities, industries, shareholders, and the species in decline. Collaboratively, the actors agree that recovering the population of the species is important; however, there are conflicting values and disagreement over what decision should be taken among the actors. For example, Actor A believes that harvesting should be prohibited, Actor B believes that the species habitat needs to be protected, Actor C believes that a stocking/reintroduction program should be established so that all other activities can remain the same, and Actor D believes that the conservation concern is not serious enough to justify actions that will have economic, social, and cultural consequences for people. Non-reducible uncertainty arises because there is no evidence that any of the proposed decisions will recover the species population, and because the socio-ecological system in question is highly complex and constantly changing. Despite conflicting values and uncertainty, a conservation decision must be taken. Collectively, the actors agree to reduce harvest and protect 5 % of the species' habitat for the next management cycle, which is a compromise from all actors that some could potentially continue to disagree with (i.e. a satisficing decision). Although they are unsure if this management decision will be successful, it is implemented, and its success will be reviewed after the management cycle to determine if the population has increased, decreased, or remained stable. After the management cycle, the success of the strategy will be evaluated, as well as if the satisficing decision is still agreeable and sufficient and if the process will begin again. This hypothetical cycle mirrors adaptive management which has been proposed as a partial solution for managing natural resource problems with wicked characteristics (see Allen et al., 2011).

[5] The term 'satisficing' is the combination of 'satisfy' and 'suffice.' A satisficing decision is one in that is agreeable to most (if not all) actors, which is deemed 'good enough' despite most (if not all) actors not viewing it as an optimal decision. This term is used in this way, in various disciplines (Prabha et al., 2007; Stüttgen et al., 2012).

Table 1
Description of how each conservation problem case study meets the criteria of *wicked conservation problems.*

Criteria	Global declines of Atlantic salmon	Agricultural activity and bats in South America	Invasion of Phragmites in North America
Possessing non-human actors, more than human actors, and human actors	**Non-humans:** Atlantic salmon, freshwater, and oceanic ecosystems. **More-than-human:** Freshwater biodiversity, oceanic biodiversity, and ecological processes. **Human:** Commercial fisheries, recreational fisheries, Indigenous fisheries, Indigenous communities, Indigenous rightsholders, landowners, regulating authorities, conservationists, and consumers (Chase, 2003; Denny and Fanning, 2016; Stensland et al., 2021)	**Non-human:** Bats (various species), forests, and ecosystems. **More-than-human:** Biodiversity and ecological processes. **Human:** Brazilian farmers, agricultural workers, government policymakers, global consumers, and conservationists (Fernandes and Watanabe, 2024; Sweigart, 2025)	**Non-human:** Flora and fauna (e.g., birds, amphibians, reptiles, mammals, fish, and invertebrates), ecosystems, and nutrient cycling. **More-than-human:** Ecosystem biodiversity and ecological processes (e.g., carbon storage, water purification). **Human:** Hunting (e.g., duck), Outdoor recreation (e.g., birdwatching, kayaking, fishing, photography, outdoor education, etc.).
Conflicting values among actors	**Commercial fisheries vs. Atlantic salmon:** The Atlantic salmon commercial fishery provides employment opportunities for local communities (e.g., Atlantic communities in Canada) and supports global food demand. Decreasing the harvestable quota of Atlantic salmon commercial fisheries may improve Atlantic salmon populations, however there would be a negative impact on local livelihoods and global food provisioning. **Hydroelectric growth vs. Atlantic salmon:** Globally, there is an increase in the demand for clean and renewable energy (e.g., hydroelectric power generation; Zarfl et al., 2015). To support this demand, free flowing rivers are often dammed. However, hydroelectric power generation has negative consequences on Atlantic salmon, such as creating migration barriers, stranding of juveniles, and turbine mortality (Scruton et al., 2008; Rubenstein et al., 2023)	**Economic growth vs. biodiversity conservation:** Agriculture drives Brazil's economy and global food supply, but deforestation harms bat populations and ecosystem services. (Fernandes and Watanabe, 2024; Sweigart, 2025; West et al., 2025; Ancillotto et al., 2019) **Local livelihoods vs. conservation:** Farmers depend on agriculture for income, while conservationists advocate for preserving habitats. (Fernandes and Watanabe, 2024; Sweigart, 2025) **Technological efficiency vs. employment:** Advances in farming technology increase productivity but reduce agricultural employment (Parré et al., 2024).	**Native Conservation vs Invasive Mitigation:** Mitigation strategies fail to target invasive Phragmites exclusively, leading to damage to native plants. A trade-off exists between invasive elimination and native conservation. **Conservation vs Financial Limitations:** Mitigation strategies are costly. Funding limitations, paired with the time sensitivity of spreading, create a challenge. **Eradication vs management feasibility:** Phragmites is a widely spread plant, it occupies several different property boundaries (private and public). A degree of collaboration must exist to mitigate the plant, but this creates complex logistics planning.
Uncertainty that is non-reducible	Atlantic salmon populations face a variety of threats, such as hydroelectric power generation (Scruton et al., 2008; Rubenstein et al., 2023), pollution (Saunders and Sprague, 1967; Watt, 1986), invasive species (Boulêtreau et al., 2018), overfishing (Parrish et al., 1998; Dadswell et al., 2022), and climate change (Walsh and Kilsby, 2007; Thorstad et al., 2021). Identifying what threats are the largest is challenging, making it difficult to reduce the cause of decline to a single threat with certainty.	Lack of comprehensive studies on the direct effects of deforestation on Brazilian bats (Mendes and Srbek-Araujo, 2021). Unpredictable ecological consequences of bat population declines (i.e. pest outbreaks and reduced pollination) (Diniz et al., 2019; Kunz et al., 2011; Liu et al., 2018). Uncertainties in global food security are influencing agricultural expansion.	Phragmites mitigation varies based on spatial and temporal factors such as native plant recovery, which is dependent on site hydrology (Rohal et al., 2019). It is unknown what the impacts on the marshland biodiversity will be as marshes vary globally.
An extended timeline with no set end	Regulating authorities set management targets at different time scales which likely do not coincide with the life cycle of Atlantic salmon. Additionally, threats to Atlantic salmon are on-going and are not easily mitigated. To ensure improvement populations will need to be evaluated at the end of every management cycle to inform the next	Deforestation and bat population declines have been occurring for decades, with agricultural expansion and economic dependency long-term trends (West et al., 2025; Dahl, 2025). Restoration or mitigation efforts for forests and bat populations also require time (years) to show results.	Even when treatment is finished and marsh is restored, some Phragmites culms remain, causing the plant to recolonize and expand in the area. Maintaining plant biodiversity requires long-term treatment applications as well as monitoring.

(continued on next page)

Table 1 (*continued*)

Criteria	Global declines of Atlantic salmon	Agricultural activity and bats in South America	Invasion of Phragmites in North America
	management decision.		
A need for a satisficing decision agreed among actors	Possible approaches include: dam removals (Hogg et al., 2015; Hill et al., 2019), removal of salmon farming, reintroduction/stocking (Saltveit, 2006; Larocque et al., 2020), fishery season closures, and habitat/water quality improvements (Koed et al., 2020; Koljonen et al., 2013).	Possible approaches include: stricter deforestation laws, agroforestry, technological innovation, and habitat restoration. In these scenarios, each solution benefits some actors but disadvantages others.	Possible approaches include: chemical controls (e.g., herbicides), mechanical controls (e.g., cutting), hydrological controls (e.g., flooding) and biological controls (e.g., plant competition).
The inability to isolate the nature of the problem	Atlantic salmon face many threats including: hydroelectric power generation (Scruton et al., 2008; Rubenstein et al., 2023), pollution (Saunders and Sprague, 1967; Watt, 1986), invasive species (Boulêtreau et al., 2018), overfishing (Parrish et al., 1998; Dadswell et al., 2022), and climate change (Walsh and Kilsby, 2007; Thorstad et al., 2021). Due to the number of threats, it is evident that there is no one problem that is directly responsible for the decline in Atlantic salmon populations and declines are a result of an accumulation of all threats.	Deforestation is tied to pasture expansion, crop production, and global market demands. With interconnected issues including, biodiversity loss, climate change, economic dependency, and global trade.	The threat is not just the plant itself but the convergence of anthropogenic stressors operating on local and global scales. This includes physical disturbances (e.g., agricultural and urban development, roadside ditches, shoreline development), eutrophication (nutrient runoff from agriculture), hydrological alteration (reservoirs and dikes, irrigated agriculture) and climate change.
No test of success	Atlantic salmon spawn from the ages of 1–10 years, depending on the geographic region (Moore et al., 1995; Klemetsen et al., 2003; Niemelä et al., 2006; Fleming and Einum, 2011). Therefore, the implementation of a new management strategy may take multiple spawning events for population improvements to be observable. Constant and continued threats (commercial fishing, hydroelectric power generation, habitat degradation) require continuous monitoring and adaptive management.	Successful bat conservation or changes to agricultural policies cannot be easily or immediately measured, with long-term ecological and economic impacts remaining uncertain.	Removal of Phragmites can cause structural changes to marshlands, which can produce mixed or inconclusive results on faunal communities. Wetland management involves actions that are irreversible, especially if they fail, so drafting a mitigation plan involves long-term monitoring. Also, Phragmites management is highly dependent on spatial and temporal factors such as site hydrology, which will affect the mitigation efforts depending on location.
Every wicked conservation problem can be considered a symptom of another problem	Threats to Atlantic salmon populations are a direct result of addressing other needs. For example, the need for clean renewable energy sources (hydroelectric power generation; Zarfl et al., 2015), income (commercial fisheries, salmon farming), and high-quality protein sources (commercial fishing, salmon farms).	Bat population decline reflects broader biodiversity loss and unsustainable land-use practices (Ancillotto et al., 2019; Frick et al., 2020; Hutson et al., 2001; Nunes et al., 2017). Deforestation for agricultural purposes reflects global food demands and economic pressures (West et al., 2025).	The dominance of the species has been attributed to survive anthropogenic changes and rapidly colonize disturbed soils (Ailstock et al., 2001). Rapid colonization occurs due to larger anthropogenic problems such as the development of shorelines (Warren et al., 2001), highways and boat transport (Hazelton et al., 2014), and declining water levels (Dinehart et al., 2023).

5. Case studies

Here, we present three case studies that fit our definition of a wicked conservation problem (see Table 1). We recognize that there are a variety of conservation problems that we could have chosen, and we intentionally selected case studies that vary in geographic scope, ecological context, and involve diverse actors to illustrate the breadth of conservation problems that can be recognized as wicked conservation problems.

5.1. Agricultural activity and bats in South America

Globally, bat populations are in decline, with over 18% listed as threatened and 23% near-threatened (Hutson et al., 2001; Ancillotto et al., 2019; Frick et al., 2020). The global decline in bat populations can be attributed to urbanization (Frick et al., 2020), deforestation (Ancillotto et al., 2019), and other anthropogenic activities (Gallo et al., 2018; Liu et al., 2018; Monck-Whipp et al., 2018; Stidsholt et al., 2024). In Brazil, bats support agricultural production by consuming agricultural pests, which has been estimated to save Brazilian farmers at least USD 390.6 million (2021) per harvest (Kunz et al., 2011; Russo and Ancillotto, 2015; Aguiar et al., 2021). Bats also support pollination and seed dispersal, which facilitates agriculture and protects biodiversity (Kunz et al., 2011; Liu et al., 2018; Diniz et al., 2019).

Despite their ecological importance (Nunes et al., 2017) and the important services bats provide to agriculture, deforestation in Brazil—often driven by agricultural expansion (e.g., agriculture-linked deforestation for cattle and crop production reached 12.8 million hectares between 2005 and 2015; West et al., 2025)—has negatively impacted bats (Threlfall et al., 2011). However, research directly linking agriculture in Brazil to impacts on bat populations is limited (Mendes and Srbek-Araujo, 2021). It is known that deforestation decreases the amount of prey available for insectivorous bats, the number of available roosts for foliage-roosting bats, and the amount of suitable foraging habitat for cluttered-environment foragers (Geggie and Fenton, 1985; Jung and Threlfall, 2018; Stidsholt et al., 2024).

Despite the negative consequences that deforestation for agriculture likely has on bat populations in Brazil, agriculture is an important component of Brazil's economy. Agriculture comprises 14.8% of Brazil's total gross domestic product with expectations to grow 5% from 2024 to 2025 (Fernandes and Watanabe, 2024; Sweigart, 2025). Since 2022, Brazil has ranked second globally in volume of agricultural goods supplied to foreign markets, with USD 138.4 billion being exported in 2024 (Dahl, 2025).

The issue of deforestation for agriculture in Brazil is a wicked conservation problem due to conflicting values and non-reducible uncertainties among bats, their conservation, and ecosystems that are reliant on them. Sustaining Brazil's agriculture-driven economy, meeting global food needs, and the need to address the priorities of diverse actors (including non-human and more than human actors) with a satisficing decision, are further evidence of this. Deforestation is decreasing roost availability and foraging habitat for bats (Geggie and Fenton, 1985; Jung and Threlfall, 2018; Stidsholt et al., 2024), which offer key ecosystem services such as pollination, seed dispersal, and pest control that support the agricultural sector (Kunz et al., 2011; Russo and Ancillotto, 2015; Liu et al., 2018; Diniz et al., 2019; Aguiar et al., 2021). Considering the ecological importance of bats and the economic importance of agriculture in Brazil, researching effective management strategies that support the goals of all actors is a challenge, supporting this as a wicked conservation problem.

5.2. Global population declines of Atlantic Salmon

Atlantic salmon (*Salmo salar*) are a commercially, recreationally, and culturally significant fish found across watersheds in the North Atlantic Ocean (MacCrimmon and Gots, 1979; Webb et al., 2007). Across their range, Atlantic salmon display different life-histories with some populations being “landlocked” and completing their entire lifecycle in freshwater, while other populations are anadromous (i.e., migration of juveniles from rivers to the ocean, followed by migration of adults from the ocean to rivers to spawn; Webb et al., 2007; Thorstad et al., 2011). The age of maturity in Atlantic salmon is highly plastic (ranging from 1 to 10 years) and individuals may spawn multiple times (Moore et al., 1995; Klemetsen et al., 2003; Niemelä et al., 2006; Fleming and Einum, 2011). Both anadromous and landlocked Atlantic salmon are declining throughout their range, with some populations already extirpated (Parrish et al., 1998; Greenberg et al., 2021; ICES, 2025). These population declines can be attributed to the construction of hydroelectric power generating stations (Scruton et al., 2008; Rubenstein et al., 2023), pollution (Saunders and Sprague, 1967; Watt, 1986), invasive species (Boulêtreau et al., 2018), overfishing (Parrish et al., 1998; Dadswell et al., 2022), salmon farming (Garseth et al., 2013; Forseth et al., 2017; Thorstad and Finstad, 2018), genetic introgression of wild salmon from farmed Atlantic salmon (Sylvester et al., 2019), invasion of ectoparasite [*Gyrodactylus salaris*] in Norwegian rivers from farmed to wild salmon (Mo, 2024), and climate change (Walsh and Kilsby, 2007; Thorstad et al., 2021).

Declines in Atlantic salmon populations across their range have negatively impacted Indigenous (Denny and Fanning, 2016), recreational (Stensland et al., 2021), and commercial fisheries (Chase, 2003) due to losses of livelihoods, high-quality protein, culture, and fishing opportunities. To mitigate population declines of Atlantic salmon, conservation efforts such as dam removals (Hogg et al., 2015; Hill et al., 2019), reintroductions/stocking (Saltveit, 2006; Larocque et al., 2020), and habitat enhancement/water quality improvements (Barlaup et al., 2008; Marttila et al., 2019) have been attempted. Some conservation actions such as the enhancement of spawning habitat (Barlaup et al., 2008) and the removal of a small dam have had positive impacts on Atlantic salmon populations (Hill et al., 2019). Although, many cases of conservation actions have failed, such as reintroductions (Saltveit, 2006; Larocque et al., 2020) and improvements to habitat and water quality (Koed et al., 2020; Koljonen et al., 2013). Overall, most populations are still at risk despite efforts of conservation action (WWF, 2001; ICES, 2025).

The global decline of Atlantic salmon populations can be considered a wicked conservation problem. Divergent actor values are exemplified by the variety of threats facing Atlantic salmon, such as the demand for clean and renewable energy (e.g., hydroelectric power generation), personal livelihoods, and global food demand (e.g., commercial overfishing and salmon farming). Multiple actors have been negatively impacted by the population declines, and mitigation efforts to improve populations are not always successful. Due to the multitude of threats facing Atlantic salmon populations, it is often difficult to quantify the impact of one single threat, leading to non-reducible uncertainty. The large geographic range, complex biology, and numerous, often concurrent threats facing Atlantic salmon make it difficult to accurately measure the effectiveness of mitigation efforts. Given the ecological, economic, and social importance of Atlantic salmon globally, there is a need to establish mitigation measures that are satisficing to actors, despite the non-reducible uncertainty of human impacts and the effectiveness of conservation efforts.

5.3. Marshland integrity threatened by Phragmites

Marshlands play an integral role in the global ecosystem. Marshlands convert solar energy into biomass that supports diverse food webs, provide important building and food resources (Al-Zaidy et al., 2019; Let and Pal, 2022), and store excess water during flood seasons, which is gradually released during dry periods (Janse et al., 2018; Al-Zaidy et al., 2019). Marshland vegetation also sequesters carbon by storing it in their underground biomass and sediments, contributing to climate change mitigation and improving water quality (Zedler and Kercher, 2005; Al-Zaidy et al., 2019; Let and Pal, 2022; Dinehart et al., 2023) while supporting high levels of biodiversity (Al-Zaidy et al., 2019).

Preserving the ecological integrity of marshlands is imperative and involves monitoring and managing invasive species like *Phragmites australis australis* (Phragmites). Phragmites in North America is a highly invasive reed of Eurasian origin that successfully outcompetes co-occurring native *Phragmites australis americanus* (Ailstock et al., 2001; Blossey et al., 2020). Phragmites proliferation has led to decreases in avian, amphibian, reptilian, mammalian, fish, and macroinvertebrate biodiversity (Keller, 2000; Warren et al., 2001; Tulbure et al., 2007; Perez et al., 2013; Frisch, 2015; Krzton-Presson et al., 2018; Dinehart et al., 2023). Dense Phragmites monocultures alter nutrient cycling due to the high uptake of nitrogen and phosphorus, increased oxygen from the rhizosphere, and increased organic matter at the end of the productive season (Findlay et al., 2003; Krzton-Presson et al., 2018). The combined effects of Phragmites make it one of the most ecologically disruptive invaders in North American marshlands.

Mitigation measures and removals of Phragmites are necessary to conserve North American marshlands. Removal strategies for invasive plants include chemical (herbicides) and mechanical interventions (mowing, grazing, tarping, burning, deseeding, flooding, and excavation; Hazelton et al., 2014). However, chemical and mechanical mitigation strategies are non-selective and negatively impact surrounding biota (Hazelton et al., 2014). Even when several mitigation strategies are combined, Phragmites is difficult to eradicate (Hazelton et al., 2014; Blossey et al., 2020; Abella et al., 2024), often returning to a site through the seedbank and existing rhizomes (Hazelton et al., 2014), or opportunistic spread in urban ecological corridors such as roadside ditches

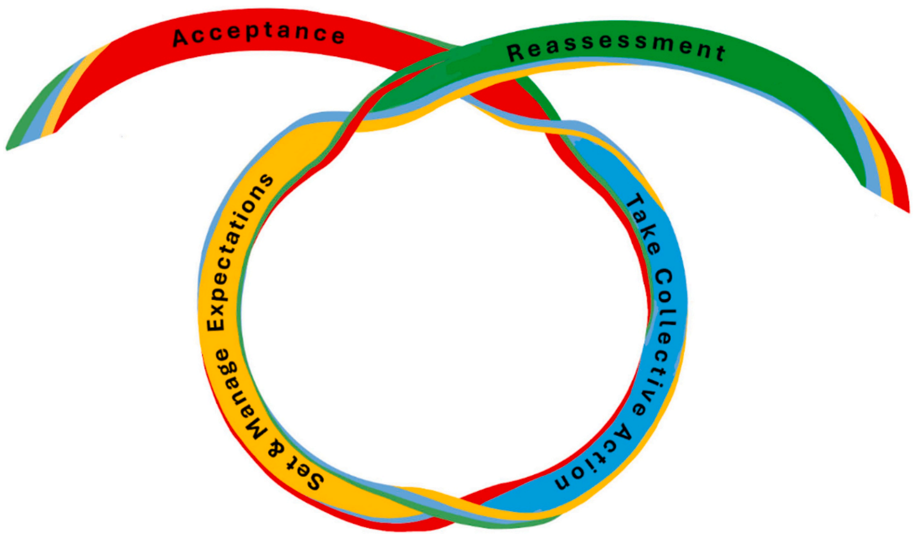

Fig. 2. Framework for Conducting Research on Wicked Conservation Problems. The framework has four recommendations: (1) accept that a conservation problem is wicked (when appropriate), (2) take collective action, (3) set and manage expectations, and (4) reassess the conservation problem as it evolves.

(Brisson et al., 2010). Phragmites can be considered a model invasive species (Meyerson et al., 2016) due to its extremely successful reproduction, both sexual and clonal, via seed dispersal, reproduction from soil seedbanks, rhizomes, stolons, and shoot nodes (Ailstock et al., 2001; Englone, 2009; Abella et al., 2024). Clonal reproduction methods are most successful, and form extremely dense stands of monotypic communities (Ailstock et al., 2001). The extensive sprawling rhizome system is key to Phragmites' dominance, allowing for greater nutrient and water uptake (Howard and Turluck, 2013; Zhou et al., 2021).

The invasion of Phragmites into North American marshlands is a wicked conservation problem due to the difficulty (if not impossibility) of eradicating the species. Mitigation also involves multiple actors with diverse goals and conflicting values (Weis et al., 2021), which have several dimensions. First, native and non-native Phragmites occupy the same ecological niche, and it is challenging to eliminate one without eliminating the other (Hazelton et al., 2014; Blossey et al., 2020). Second, Phragmites removal is costly, labor-intensive, and often fails to achieve eradication, signaling a need for ongoing management and long-term monitoring (Hazelton et al., 2014). This creates tension between ecological and economic priorities. Phragmites invasion may also necessitate complex collaborations and/or satisficing decisions, as Phragmites is widely distributed across both private and public lands. The success or failure of Phragmites is constrained not only by mitigation strategies but also by spatial and temporal factors (Rohal et al., 2019). Phragmites invasion is also a symptom of broader issues driven by anthropogenic activities, including nutrient enrichment and altered hydrology (Dinehart et al., 2023).

6. Conducting research on *Wicked Conservation Problems*

To support knowledge generators (e.g., researchers, academics, community leaders) researching wicked conservation problems, we outline a *Framework for Conducting Research on Wicked Conservation Problems* (Fig. 2). We recommend that knowledge generators (1) accept that a conservation problem is wicked (when appropriate), (2) take collective action, (3) set and manage expectations, and (4) reassess the conservation problem as it evolves.

6.1. Accept that a conservation problem is wicked

Acceptance is the first component of our framework. To apply a wicked problems lens, researchers must first acknowledge and accept that the conservation problem they are beginning to study is a wicked conservation problem (assuming it is indeed a wicked problem). Acceptance begins with a deep understanding of wicked problems (Rittel and Webber, 1973) and the definition of a wicked conservation problem. Next, researchers must determine if the conservation problem indeed qualifies as a wicked conservation problem (i.e., if most criteria are met). Acceptance also involves acknowledging that responses to the wicked conservation problem will not be optimal for all actors (i.e., non-human, more than human, and human actors) and must instead be *satisficing*. The wicked conservation problem will also not be solved definitively, and this may be difficult for conservation researchers to accept. This means that the researcher needs to gather data and understand the conservation problem in its entirety before beginning to work towards conservation solutions. Acceptance also involves acknowledging that no single entity can effectively research or manage a wicked conservation problem alone. The wickedness of the problem guarantees that research will need to be collaborative and involve all relevant actors, accepting that conducting research on a conservation problem alone will not lead to further understanding and may amplify the wickedness of the problem. When all of this has been accepted, research with a wicked conservation problems lens can begin.

6.2. Take collective action

After a conservation problem has been identified and accepted as a wicked conservation problem, collective action is the next step. The role of the researcher can vary depending on the wicked conservation problem. Researchers' roles can be research-focused where they conduct data analysis, scoping reviews, research reports, or other scholarly material. Researchers can also act as honest brokers (Levin et al., 2021), where their role is to mobilize knowledge and act as a trusted standalone entity. In a scenario where more evidence is required before a research-based decision can be made, we suggest co-production and co-evolution (Haverkort and Rist, 2004; Bartlett et al., 2012; Reid et al., 2021) with relevant actors. This includes creating pathways for relevant actors such as local communities, knowledge holders, Indigenous communities and rightsholders, governments, and any other actors impacted by the wicked conservation problem. This ensures that decisions are as informed as possible, and also fair, equitable, and transparent despite divergent values (Biggs et al., 2011). In the more likely scenario that enough evidence exists to inform the wicked conservation problem, it should be synthesised to ensure that it is accessible for all relevant actors (Sutherland et al., 2017). We then propose that all relevant actors engage in co-assessment to inform the most agreeable

Box 1
Using our proposed framework to support conservation research on bat declines due to agriculture in Brazil.

Accept that a Conservation Problem is Wicked: Declines in Brazilian bat populations are linked to global drivers such as habitat loss and degradation (Frick et al., 2020; Ancillotto et al., 2019), with these pressures intensified by the extensive area of land devoted to agriculture in Brazil (Threlfall et al., 2011; Mendes and Srbek-Araujo, 2021; Fernandes and Watanabe, 2024). Researchers seeking to understand how forestry practices contribute to bat population declines and how they alter bat movement patterns should look to engage with local actors to understand this problem and ultimately recognize these declines as a wicked conservation problem. Given the global scope of agriculture, involving all stakeholders is unrealistic. Instead, researchers should convene local farmers, bat researchers, conservationists, local government representatives, forestry professionals, and other relevant community members. These discussions can raise awareness of bats' often-overlooked contributions to agriculture, examine the causes and consequences of population declines, and recognize the shared responsibility of multiple actors for impacts on bat populations and surrounding ecosystems. Importantly, some stakeholders, particularly forestry professionals whose livelihoods, economic interests, or established management practices may be affected by conservation measures, may be reluctant to support changes or ultimately oppose any changes, potentially leading to entrenched conflicts. By facilitating learning, dialogue, and mutual recognition of competing interests, researchers can help foster collaboration to restore, conserve, and rebuild the ecosystems on which both bats and people depend, while looking toward conservation research for answers.

Take Collective Action: Actors who agree to participate and recognize Brazilian bat population declines as a wicked conservation problem would engage in collective action. Researchers would facilitate the co-production of knowledge by bringing together scientific evidence, local knowledge, and stakeholder preferences. For example, scientists may share innovations in sustainable agricultural practices that capitalize on bats' roles in pollination, seed dispersal, and pest control (Kunz et al., 2011; Liu et al., 2018; Diniz et al., 2019; Russo and Ancillotto, 2015; Aguiar et al., 2021), while local farmers can contribute practical knowledge to refine these approaches. Government representatives can provide insight into the economic importance of agriculture and its role in supporting food production and trade. For this process to be successful, actors must recognize the legitimacy of differing perspectives; for instance, conservationists and researchers must acknowledge the importance of agriculture to local livelihoods, while agricultural actors, particularly forestry professionals who may be reluctant to alter established practices, must recognize the ecological and economic benefits bats provide. Such competing priorities may lead to value-based and persistent conflicts, but a collaborative process grounded in transparency, mutual learning, and respect for diverse forms of knowledge can help build trust and identify solutions that balance conservation and agricultural objectives.

Set and Manage Expectations: Next, actors would work with researchers to set and manage expectations. Because researchers possess expertise in bat ecology, conservation planning, and the social and ecological dimensions of environmental management, they can help stakeholders understand the constraints and opportunities associated with different management options. For example, researchers can help actors recognize that some seemingly optimal outcomes, such as large-scale conversion of agricultural land to other ecosystems, may not be feasible in the short term. Instead, stakeholders would work together to identify a satisficing decision, one that represents a practical step toward more effective management and is acceptable to all parties for the moment, with continual reassessment and trade-offs needed on these decisions. Researchers would facilitate these discussions and help integrate ecological, social, and economic considerations into decision-making. For Brazilian bat conservation, the long-term goal should be incremental progress that includes diverse actors in commercial and governmental decisions and ensures that the interests of non-human stakeholders affected by ecosystem change are represented. In this way, success is reframed as a series of achievable improvements that balance ecological recovery with community and economic needs.

Reassess the Conservation Problem: In this scenario, no ultimate solution exists, but collaboration among actors can lead to more effective management over time. Researchers would play a key role in facilitating ongoing reassessment as stakeholder preferences and the conservation problem evolves. Drawing on expertise from fields such as ecology, the social sciences, and the humanities, researchers can work with local communities to highlight the importance of bat populations and the ecosystems they support, ensuring actors maintain a shared understanding of why conservation matters. During each reassessment, actors would consider questions such as: Have Brazilian bat populations improved? Are current management strategies effective? Have new conflicts emerged? Are proposed developments likely to affect bat populations? As outlined in our Framework for Conducting Research on Wicked Conservation Problems, this process is continual and has no fixed endpoint; even if bat populations recover, researchers and stakeholders would need to continue monitoring conditions and consulting with one another to support their long-term conservation.

future management strategy (Sutherland et al., 2017). Co-producing knowledge, guided by researchers, will ensure all relevant information on the conservation problem will be addressed with all relevant actors, leading to informed decision-making and promoting the formation of common interests and understanding (Castleden et al., 2012). This will also promote bottom-up solutions that empower actors to make evidence-informed decisions with support and guidance from research. This kind of collective action may also foster mutual trust, new relationships, and further shareholder buy-ins. However, we would like to note that collective action may not be immediately possible under circumstances of entrenched disagreements. In this scenario, we recommend mediated conversations but recognize that even satisficing decisions may not be possible (for an example on entrenched disagreements, see conflicts over grouse shooting and raptor persecution in the UK (Thirgood et al., 2000; Hodgson et al., 2018; Ewing et al., 2023)) and needs to be continually evaluated and reflected upon among actors to ensure it remains a satisficing decision even though some actors may continually oppose it. Actors, in this scenario, need to recognize that the satisficing decision is inherently subjective in nature, as an inevitable consequence of conflicting values among actors, with constant re-evaluation and compromise needed. Mediated conversations on a frequent basis can be helpful in this regard.

6.3. Set and manage expectations

When setting goals for conservation research, we must consider all perspectives and integrate them into a coherent research vision. Wicked conservation problems involve non-reducible uncertainty, conflicting values, no single "correct" solution, and the expectation of the researchers should not be to find a single, ultimate solution to the conservation problem. When setting expectations, researchers must include the perspectives of Indigenous communities and rightsholders, local actors, and larger government and regulatory bodies. Indigenous communities and rightsholders can provide profound ecological knowledge of lands, which can help to fill knowledge gaps and offer perspectives that differ from those of Western scientists (Wheeler and Root-Bernstein, 2020). Working alongside Indigenous communities and rightsholders, as well as local actors can help address underlying conflicts, ensure goals are locally relevant, and establish context-appropriate objectives. Working collaboratively will also prevent researchers from seeking an impossible "optimal" solution and promote finding a satisficing" set of decisions and goals for managing a wicked conservation problem (Balint et al., 2011). Setting these goals will also help manage expectations of all actors over time.

6.4. Reassess the conservation problem

Finally, we recommend that researchers reassess the uncertainties inherent in the initial wicked conservation problem, as well as the divergence or convergence of values among actors, which ultimately can prove unsolvable with no agreeable decision. It is essential not to reduce management of a wicked conservation problem to a scientific exercise, and to recognize and engage with ethical and everyday aspects of conservation. In this reassessment, researchers should consider the following questions in their research: How has the problem changed since our first assessment of it? What parts of the problem do we understand now? What new knowledge gaps did we identify? What are the barriers to more effective management? Is there still not enough data? Is there still not enough agreement on values to move forward? To answer these questions and engage in reassessment, we suggest not only re-consulting with actors, such as local communities, organizations, governments, Indigenous communities, rightsholders, and organizations,

Box 2
Using our proposed framework to support conservation research on declines of Atlantic salmon in Eastern Canada.

Accept that a Conservation Problem is Wicked: In the case of Atlantic salmon population declines, we can look to cases such as those in Atlantic Canada, where there are large declines of Atlantic Salmon in systems like the Miramichi River in New Brunswick (Chaput et al., 2016). Here, a researcher is interested in studying their decline and understanding how to conserve their populations for the future. In this scenario they could bring together actors to engage with one another, explicitly acknowledging and accepting that Atlantic salmon declines are a wicked conservation problem. Declines in salmon populations are largely due to historic overfishing, habitat fragmentation, forestry practices, pollution, and salmon farming (see section 5.2). Drawing on their understanding of the ecological and social dimensions of the problem, researchers can help stakeholders develop a shared understanding of these interconnected drivers and their consequences. Actors that would need to convene and form a common understanding of this problem include Indigenous communities (such as Mi'kmaq First Nations whose territory is along the Miramichi River), fisheries managers (including government representatives at both provincial and federal levels), non-governmental organizations (e.g., the Miramichi Salmon Association), commercial fishery representatives (e.g. commercial fishers and fish farmers in Atlantic Canada), hydroelectric representatives, and various local community actors. Researchers would facilitate dialogue among these groups, as an honest broker, encouraging participants to recognize that multiple actors are responsible for impacts on non-human actors, including Atlantic salmon populations and the environment. This simple act of recognition could empower actors to collaborate, and restore, rebuild, and conserve Atlantic salmon and the environments they rely upon.

Photo provided by Andrew Howarth.

Take Collective Action: All actors—who agree to participate and recognize declines of Atlantic salmon populations as a wicked conservation problem—would take collective action. Researchers would facilitate the co-production of knowledge by bringing together scientific evidence, Indigenous knowledge, non-Indigenous local knowledge and collect information on actor preferences and stakeholder values. For example, community representatives could share how their family histories link back to harvesting practices and how their families for generations relied on fishing as a source of income, and Mi'kmaq First Nation community members could share, when they wish to and on their own terms, the importance of Atlantic salmon to their history and how they are connected to non-human kin through traditional stories. Government representatives and private sector workers could also share how infrastructure such as dams have affected Atlantic salmon populations, yet provide essential services to the larger population, and how forestry in the region provides an essential contribution to the Canadian economy. By creating opportunities for knowledge sharing and dialogue, researchers can help actors develop a more comprehensive understanding of the social and ecological dimensions of salmon declines. In this context, all actors would need to genuinely recognize the importance of each other's perspective. For example, actors wanting primarily to conserve Atlantic salmon populations (e.g., Indigenous communities, local conservation organizations, fishers who rely on healthy salmon populations) would need to recognize the importance of built infrastructure, such as hydroelectric dams, which power the communities in which they live. This collaborative process would ensure transparency and build shared understanding and trust among actors despite their differing values.

Photo provided by Andrew Howarth.

Set and Manage Expectations: Next, actors would work to set and manage expectations. Researchers, drawing on their expertise in salmon ecology, conservation planning, and stakeholder engagement, can help actors understand the constraints and opportunities associated with different management options. For example, certain stakeholders would need to accept that some seemingly optimal outcomes, like the removal of hydroelectric dams or full population recoveries, may not be feasible in the short-term. As such, actors would need to come together and identify 'solutions' (i.e., steps toward more effective management of the problem) that would be satisficing to all. At this stage, it may be revealed that Indigenous and local communities were not adequately consulted during infrastructure development in the region, and where they were consulted, their perspectives were not genuinely taken into consideration. A goal for all could then be to tackle Atlantic salmon conservation one step at a time, where there are more community-level actors present in commercial and governmental decisions, to advocate for the non-human actors that are affected by developments in the region. In this way, success is reframed as incremental improvements that balance ecological recovery with social and economic needs.

Photo provided by Andrew Howarth.

Reassess the Conservation Problem: In the scenario we are presenting, no single and definitive solution is possible, but ongoing collaborations by all actors may lead to more effective management of the problem. This collaboration would include reassessing the conservation problem as actor preferences and the problem itself evolve. Researchers would play a key role in facilitating this reassessment process by helping actors monitor ecological and social changes, synthesize new information, and maintain dialogue among stakeholders. Relevant researchers (such as those in the social sciences and humanities) and Mi'kmaq First Nations and local communities could come together to recount the importance of the non-human and more-than-human actors and present this information to all parties, ensuring that everyone maintains their shared understanding of why Atlantic salmon are important to different parties and providing a record of these stories and findings (for example, see Jeane, 2025). During each reassessment process, several key questions (such as the following) would need be answered: Have Atlantic salmon populations improved? Are current management strategies effective? Have any new conflicts emerged among

(*continued on next page*)

Box 2 (*continued*)

actors? Are any new projects being planned that could affect Atlantic salmon populations? Researchers can support these evaluations by collecting and interpreting ecological and social data and communicating findings to stakeholders. As noted in our Framework for Conducting Research on Wicked Conservation Problems, this cycle is continual and, like the problems it revolves around, has no set endpoint; even if Atlantic salmon populations were to grow, actors would continually need to consult with one-another to ensure that they are maintained and that future management decisions would not negatively impact populations.

Box 3

Using our proposed framework to support conservation research on marshland integrity threatened by Phragmites.

Accept that a Conservation Problem is Wicked: In the case of the invasion of *Phragmites australis australis* (Phragmites) in North America, particularly in the Laurentian Great Lakes region where dense monocultures threaten ecologically significant coastal marshes (Tulbure et al., 2007). Here, a researcher is interested in understanding removal methods that can help control the invasion of Phragmites to protect marshland integrity. Marshland integrity has been threatened by the invasion of Phragmites which has resulted in decreases in marshland biodiversity and alteration to nutrient cycling (see section 5.3). Researchers can then identify and convene relevant actors, including conservation authorities, local municipalities, park and protected area managers, Indigenous communities, and local residents. When the relevant actors convene it is critical that the researchers explicitly acknowledge and accept that the invasion of Phragmites in the Laurentian Great Lakes region as a wicked conservation problem. Researchers would need to facilitate discussions among actors encouraging participants to recognize that multiple actors are responsible for the invasion of Phragmites in the Laurentian Great Lakes region. These discussions would hopefully empower actors to set realistic goals, strengthen collaboration among actors, and improve efforts to restore and conserve the integrity of marshland ecosystems.

Take Collective Action: All actors— who agree to participate and recognize the threat to the integrity of Laurentian Great Lake marshland as a wicked conservation problem— would take collective action. Researchers would facilitate the co-production of knowledge by bringing together existing information, integrating diverse knowledge systems (e.g., scientific data, Indigenous knowledge, and non-Indigenous local knowledge), and identifying stakeholder values and preferences. For example, researchers may contribute scientific evidence on the ecological impacts of Phragmites and the effectiveness of different management approaches, while Indigenous communities and local residents can provide place-based knowledge of ecosystem change, species distributions, and past management efforts. By creating opportunities for knowledge sharing and mutual learning, researchers can help actors develop a more comprehensive understanding of the invasion, build trust among actors, and identify management actions that are both ecologically effective and socially acceptable.

Set and Manage Expectations: Researchers would help actors evaluate the costs, benefits, and trade-offs of different management strategies, such as habitat disturbance from mechanical removal, contamination risks associated with chemical control, and the ecological consequences of inaction. By synthesizing available evidence and facilitating discussion, researchers can help stakeholders recognize that conflicting values are an inherent feature of wicked conservation problems. Rather than pursuing an optimal solution, actors would work with researchers to identify satisficing decisions and goals that balance competing priorities. For example, stakeholders may choose to contain the spread of Phragmites by managing patch edges and new infestations rather than attempting to eradicate large established stands. Researchers can support the implementation and evaluation of these strategies, while annual meetings allow actors to assess progress and adapt management decisions as conditions change.

Reassess the Conservation Problem: In this scenario, there is no single solution to the invasion of Phragmites at large spatial scales. Instead, researchers would facilitate ongoing collaboration and reassessment as both stakeholder priorities and the invasion itself evolves. Working with stakeholders, researchers can help maintain a shared understanding of the ecological and social impacts of Phragmites and document how these impacts affect both human and non-human actors. During each reassessment, actors would consider questions such as: Is Phragmites spreading? Are current management strategies effective? Have new conflicts emerged? Are planned projects likely to facilitate further spread? As outlined in our Framework for Conducting Research on Wicked Conservation Problems, this process is continual and has no fixed endpoint. Researchers and actors would need to work together through long-term monitoring and regular consultation to ensure management progress is maintained and future decisions do not undermine past successes.

but also collaborating with researchers in the humanities who are trained to investigate the 'values dimension' of the problem and other non-reducible uncertainties beyond the scope of trained scientists. Humanities perspectives can highlight value conflicts, ethical trade-offs, and non-reducible uncertainties, thereby offering insights that complement natural scientific and social scientific efforts. In this context, authorities on ethics and values can provide crucial assistance by simply starting conversations that scientists rarely start or are generally unqualified to lead. This engagement is particularly necessary when divergent values (not non-reducible uncertainties) are the main barrier to effectively managing a wicked conservation problem. In the past, research on these problems has been dominated by 'facts-based' understandings (Buschke et al., 2019). Ensuring that wicked conservation problems are approached by interdisciplinary groups will allow conservation strategies to be grounded in both ecological science and human values.

7. Applying our framework for conducting research on wicked conservation problems

Our Framework for Conducting Research on Wicked Conservation Problems can be applied as a structured, iterative process to engage researchers and actors in wicked conservation problems. In this process, researchers begin by recognizing and accepting the problem as a wicked one and acknowledging its wicked aspects (e.g., nonreducible uncertainty, lack of definitive solutions, need for collective action). Researchers then work with relevant actors to co-produce or synthesize knowledge, ensuring that diverse (and possibly divergent) perspectives and scientific evidence inform decision-making. Realistic, shared goals are then established based on what is satisficing (as opposed to optimal) for actors, and expectations are managed accordingly. Finally, the problem and its satisficing decisions are periodically reassessed to incorporate new knowledge, address emerging uncertainties, and reflect evolving values. As these satisficing decisions are not optimal for a single group and will likely be contested by certain actors, they also need to be continually evaluated as the problems evolve over time, to ensure that they continue to be satisficing for most actors. As new knowledge or situations arise, the satisficing decisions need to be re-evaluated, through the cyclical process of wicked conservation problems.

In the next section, we demonstrate how our Framework for Conducting Research on Wicked Conservation Problems could be applied to our case studies introduced in Section 5, the three examples are outlined in Boxes 1 (Agriculture and bats in South America), 2 (Atlantic salmon population in Atlantic Canada), and 3 (Phragmites invasion around the Laurentian Great Lakes).

8. Conclusion

In this paper, we provided an overview of 'wicked problems theory' and thinking in the context of conservation. Conservation problems have often been mis- or under-identified as wicked problems, and the concept of wicked problems is often mis- or under-used to describe conservation problems. Recognizing this, we defined wicked conservation problems with eight criteria that embrace and modify past definitions of wicked problems. We propose understanding wicked conservation problems through the *Wicked Conservation Problems Spiral,* which describes and visualises the complex process of addressing wicked conservation problems while recognizing the importance of diverse values and including multiple actors when researching the problem. To support our ideas, we provided three case studies that exemplify how past and current conservation issues can be thought of and approached more holistically using wicked problems thinking and our definition of wicked conservation problems. To facilitate effective research on wicked conservation problems, we provided a framework for *Conducting Research on Wicked Conservation Problems* that aims to facilitate relationship building, foster trust among actors, and inform more successful management of the wicked conservation problem. We hope that this paper will provide context and guide research on wicked conservation problems, thereby supporting practitioners who must make the most informed decisions they can, to benefit both people and nature.

CRediT authorship contribution statement

Raegan Davis: Writing – review & editing, Writing – original draft, Investigation, Visualization. **Tamara Donnelly:** Writing – review & editing, Writing – original draft, Investigation, Visualization. **Brenna Hynes:** Writing – original draft, Investigation. **Karolyn McGovern:** Writing – original draft, Visualization, Investigation. **Douglas Strick:** Writing – original draft, Investigation. **Madison Empey:** Writing – original draft, Investigation. **Steven J. Cooke:** Writing – review & editing, Supervision, Conceptualization. **Andrew Howarth:** Writing – review & editing, Supervision, Investigation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors of this paper declare that no use of generative AI in the preparation of this manuscript.

Funding

This project had no funding.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgements

We would like to acknowledge Dr. Vivian Nyguen for her thoughtful feedback on the preparation of this manuscript.

Data availability

No data was used for the research described in the article.

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