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Prevalence and Implications of "Must-Kill" Angling Regulations for the Management of Invasive Fishes

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ABSTRACT

Freshwater biodiversity is increasingly threatened by invasive species, which can disrupt native fish populations and the fisheries they support. Must-kill regulations, which prohibit the live release of invasive fish caught by recreational anglers, are a management strategy that can be implemented to limit the negative effects of invasive fish populations. Our review of angling regulations around the globe revealed that must-kill regulations for numerous species were frequently enacted in countries including Canada, Japan, and the USA. Suggested benefits of must-kill regulations included limiting invasive species population size and preventing their dispersal, among others. While these benefits were plausible, we found no rigorous assessments of their effectiveness. Moreover, must-kill regulations can introduce concerns such as angler opposition and species misidentification. Here, we bolstered sparse evidence with anecdotes and perspectives to identify potential advantages and drawbacks of must-kill regulations. We also provided guidelines for implementing must-kill regulations that emphasize strategies to increase the likelihood of success while minimizing unintended consequences. Specific guidelines vary depending on management objectives, but generally include a preliminary feasibility and risk assessment followed by post-implementation monitoring of efficacy and consequences.

1 | Introduction

Freshwater biodiversity provides critical ecosystem services for people around the globe (Lynch et al. 2023), yet it is declining at alarming rates (over 80% since the 1970s; WWF 2020). These declines affect a wide range of taxa, including plants, amphibians, and many others, but fish are often a focal point of conservation concerns due to their ecological, economic, and cultural significance in recreational and subsistence fisheries (Arlinghaus and Cooke 2009; Cooke et al. 2015; Lynch et al. 2016; Noble et al. 2016). About 25% of freshwater fish species are threatened with extinction (Sayer et al. 2025), primarily from habitat degradation, climate change, overexploitation, and invasive species (Arthington et al. 2016; Reid et al. 2019). Among these threats, the impacts of invasive species continue to expand, as nonnative aquatic species are introduced at alarming rates (Thomaz et al. 2015). Herein, we define invasive species as introduced species with established populations outside of their native range that can spread rapidly and negatively affect recipient ecosystems (Havel et al. 2015; Thomaz et al. 2015).

Invasive fishes are of particular conservation concern because they often disrupt native fish populations through competition and predation, sometimes leading to severe socioeconomic consequences (Britton et al. 2011; Cambray 2003; Gozlan et al. 2010; Mills et al. 2004). Their continued spread is facilitated by anthropogenic activities such as illegal stocking (e.g., pet dumping, releasing baitfish, or for angling; Strecker et al. 2011; Anderson et al. 2014; McEachran et al. 2022) and accidental transportation (e.g., via ballast water or bait-bucket

transfers; Litvak and Mandrak 1993; Bailey 2015). Regardless of introduction pathways, various management strategies are often implemented to mitigate the negative effects of invasive fishes, with goals ranging from containment to complete eradication. Common removal techniques include chemical treatments, electrofishing, and passive methods such as gill netting (reviewed in Rytwinski et al. 2019; Klein et al. 2023). Oftentimes, angling regulations prohibit the live release of invasive species by requiring anglers to kill them upon capture (Johnson et al. 2009; Klein et al. 2023). These regulations are referred to as "must-kill" (used throughout this manuscript), "mandatory kill," "mandatory retention," or "catch-and-kill" regulations.

Must-kill regulations are widespread, including round gobies (*Neogobius melanostomus*) in Ontario, Canada (OMNRF 2025), largemouth bass (*Micropterus nigricans*) in several prefectures of Japan (Rahel and Taniguchi 2019), common carp (*Cyprinus carpio*) in New Zealand (Freshwater Fisheries Regulations Section 67B), and northern pike (*Esox lucius*) in California, USA (California Code of Regulations Title 14), among others (Table S1). Must-kill regulations are often considered a cost-effective supplement to other removal strategies (Klein et al. 2023), but may be the only feasible suppression method for some species. Proposed benefits of must-kill regulations include limiting invasive species population sizes and preventing their spread (Johnson et al. 2009; Klein et al. 2023; Rahel and Smith 2018). However, potential drawbacks must also be considered.

Herein, we reviewed instances of must-kill regulations around the globe. Subsequently, we critically evaluated examples where must-kill regulations may have had an impact. Finally, we discussed the potential benefits and drawbacks of must-kill regulations (Table 1) by exploring supporting evidence and highlighting knowledge gaps. Rather than normatively categorizing must-kill regulations as "good" or "bad" we identified key factors that should be considered prior to implementation to prevent unintended consequences. Where must-kill regulations were implemented, we discussed actions that can be undertaken to mitigate potential drawbacks. In doing so, we outlined avenues for future research to enhance the evidence base, enabling more informed management decisions regarding when and when not to enact must-kill regulations.

2 | Prevalence of Must-Kill Regulations

To assess the prevalence of must-kill regulations, we reviewed regional fishing regulations across the globe and searched the internet using keywords ("must kill," "mandatory kill," "mandatory retention," "catch and kill," "prohibited release") on Google Scholar. The search was limited to regulations written in English or French and those that could be translated into English. We identified must-kill regulations in six countries (Table 2). The number of species subjected to must-kill regulations was lowest in New Zealand and France, where must-kill regulations applied across the entire country. In contrast, in countries where must-kill regulations included more species, such as Canada, Japan, and the USA, must-kill regulations tended to apply to smaller regions (provinces, prefectures, or states, respectively) and some specific waterbodies (Table 2). Species most commonly subjected to must-kill regulations included bluegill (*Lepomis macrochirus*), largemouth bass, northern pike, northern snakehead (*Channa argus*), smallmouth bass (*Micropterus dolomieu*), and walleye (*Sander vitreus*; Table S1).

3 | Associations With Management Success

Must-kill regulations were often discussed as a cost-effective management strategy to provide numerous benefits for invasive species management (Table 1; Johnson et al. 2009; Rahel and Smith 2018). Implementing must-kill regulations can be less expensive than other removal techniques, such as intensive gill netting programs, which often cost millions of dollars annually. For example, over $2.5 million USD was spent on gill netting invasive lake trout (*Salvelinus namaycush*) in Yellowstone Lake (Wyoming, USA) in 2019 (Koel et al. 2020). In many instances, must-kill regulations were enacted to support other active removal strategies. Although we were unable to find any rigorous assessments verifying the

TABLE 1 | Potential pros and cons of must-kill angling regulations for the management of invasive fishes.

Pros	Cons
May reduce invasive fish population size, mitigating negative ecological effects	May be ineffective at significantly reducing invasive fish populations in certain instances
May contribute to preventing the spread of invasive fish between waterbodies	Reducing invasive fish population sizes may not always result in proportional ecological benefits
Can provide socioeconomic benefits by promoting new fisheries	May lead to noncompliance if anglers value the invasive species' fishery
Cost-effective compared to other removal strategies	Raises ethical concerns
Engages anglers in conservation efforts	Risk of species misidentification, leading to accidental culling of native species or release of invasive species
	May mitigate any ecological benefits that the invasive species provides
	May limit angling opportunities for those opposed to killing invasive fish
	Could negatively impact public perception of recreational angling

Note: Many of these potential pros and cons have not been systematically assessed and are outcomes that may or may not occur based on context-dependent factors.

TABLE 2 | Locations, species, and jurisdictional level of must-kill regulations in the world.

Location	Number of species	Jurisdiction[a]
Australia	8	Province-wide
New South Wales	1	
Queensland	6	
South Australia	5	
Victoria	3	
Canada	21	Province-wide
Alberta	1	
Nova Scotia	2	
Ontario	19[b]	
France	8[b,c]	Country-wide
Japan	12	Mixed (see below)
Akita	4	Prefecture-wide
Fukushima	3	Prefecture-wide
Gifu	1	Prefecture-wide
Gunma	1	Prefecture-wide
Hiroshima	3	Waterbody-specific
Iwate	2	Prefecture-wide
Kagoshima	3	Waterbody-specific
Kanagawa	3	Prefecture-wide
Kumamoto	6	Waterbody-specific
Miyagi	3	Prefecture-wide
Nagano	3	Prefecture-wide
Niigata	3	Prefecture-wide
Saga	7[d,e]	Prefecture-wide
Saitama	5	Prefecture-wide
Shiwa	2	Waterbody-specific
Tochigi	1	Prefecture-wide
Tottori	3	Prefecture-wide
Yamagata	3	Prefecture-wide
Yamanashi	3	Prefecture-wide
New Zealand	2	Country-wide
United States of America	27	Mixed (see below)
Alaska	1	Region-specific
Arkansas	1	State-wide
California	3	State-wide
Delaware	3	State-wide
Louisiana	5	State-wide
Missouri	1	State-wide
Montana	4	Waterbody-specific
New Jersey	11	State-wide
New York	1[b]	State-wide
South Carolina	1	State-wide
Utah	8	State-wide and Waterbody-specific
Wyoming	8	State-wide & Waterbody-specific

[a]For references and specific species for all regulations, please refer to Supporting Information.
[b]All snakehead spp. (Family Channidae) are subjected to must-kill regulations in the region but were included as one species in these counts.
[c]All moroko spp. (Genus *Pseudorasbora*) are subjected to must-kill regulations in the region but are included as one species in these counts.
[d]All gar spp. (Family Lepisosteidae) are subjected to must-kill regulations in the region but were included as one species in these counts.
[e]All pike spp. (Family Esocidae) are subjected to must-kill regulations in the region but were included as one species in these counts.

effectiveness of must-kill regulations, must-kill regulations have been associated with regulatory success (i.e., decreased ecological impacts of invasive species). However, a cause–effect relationship is difficult to establish between must-kill regulations and regulatory success because multiple management strategies often co-occur.

Must-kill regulations often co-occurred with other management strategies. For example, high numbers of invasive lake trout in Yellowstone Lake (Wyoming, USA) threatened native cutthroat trout (*Oncorhynchus clarkii*) through competition and predation (Koel et al. 2005). To conserve native cutthroat trout, must-kill regulations and a long-term gill netting program were instituted to limit lake trout abundance. Overall, management actions were successful in reducing lake trout abundance throughout the 2010s, facilitating increased cutthroat trout abundance (Koel et al. 2020). However, angler harvest removed only 3% of the vast number of lake trout removed by gill netting from Yellowstone Lake in 2016 (Arnold et al. 2017). Although must-kill regulations may have added sufficient lake trout harvest to contribute to the increase in cutthroat trout abundance, the same results may have been achieved by gill netting alone. In the future, data from stock assessments could potentially be used to understand to what degree must-kill regulations contributed to native species recovery (if must-kill harvest is quantified through creel surveys). Additionally, must-kill regulations have often been enacted to prevent the spread of invasive species, such as for northern pike in California, USA, which have remained eradicated since 2007 (Dunker et al. 2018). Again, the extent to which must-kill regulations contributed to this lack of dispersal and reestablishment is difficult to establish.

Uncertainties highlight the need for future research to directly assess the effectiveness of must-kill regulations in achieving

management objectives. Methods to assess effectiveness vary among different management goals. Although the potential benefits of must-kill regulations may be numerous, the lack of rigorous evidence for their success in published literature led us to discuss potential drawbacks that were underrepresented in fisheries literature. In doing so, we hope to encourage further consideration and awareness of these drawbacks, provide insight for fisheries managers considering must-kill regulations, and inspire future research to fill existing knowledge gaps.

4 | Limiting Population Size

Perhaps the most obvious potential benefit of must-kill regulations is to control invasive species population sizes through increased angler harvest and fishing mortality. Given that the overarching goal of such regulations should be to reduce the negative ecological impacts of invasive fish, this benefit's validity depends entirely on the assumption that additional harvest by anglers causes a reduction in population size of sufficient magnitude to limit the negative effects of the invasive species. Negative effects of invasive species are assumed to decrease with population size. In such cases, managers must ensure that angler harvest reaches levels sufficient to induce ecologically relevant population declines. If achieved, must-kill regulations would be a cost-effective management technique to mitigate the negative effects of invasive fish. However, achieving sufficient population declines through must-kill regulations is not straightforward because increasing angling effort does not always diminish population size due to changes in catchability by angling-induced selection (Philipp et al. 2009) and compensatory responses in earlier age at maturity (Zarri et al. 2025), among other factors.

Must-kill regulations often rely on anglers catching invasive fish as bycatch, rather than as a primary target, which can limit harvest rates or lead to selective exploitation of certain phenotypes (Klein et al. 2023), thereby potentially producing counterproductive results due to compensatory responses (Zarri et al. 2025; Závorka et al. 2018). For instance, size-selective harvest of large-sized fishes decreases size-at-age without necessarily decreasing population size (Heino et al. 2015; Jørgensen et al. 2007; Monk et al. 2021; Swain et al. 2007). Similarly, invasive pumpkinseed (*Lepomis gibbosus*) in France subjected to must-kill regulations were often caught as bycatch by anglers targeting larger cyprinids. Because fishing for large cyprinids typically required large hooks, only large pumpkinseeds were removed, which led to a reduction in average size (with potential for early maturation; Aday et al. 2009) but no decline in abundance (Evangelista et al. 2015). Further, biomass of invasive northern pikeminnow (*Ptychocheilus oregonensis*) in British canals remained stable, despite increased angler harvest of large individuals (Smith et al. 1996). Where invasive species are a primary target, angler harvest is often also insufficient to significantly reduce population size (Pasko and Goldberg 2014; Rahel and Smith 2018). For example, 3 years of selective angler harvest of invasive brook trout (*Salvelinus fontinalis*) in Alberta, Canada, had minimal impact on population size (Paul et al. 2003). These examples highlight a key challenge that must-kill regulations do not always translate into effective population control.

If insufficient harvest or compensatory mechanisms mitigate the success of must-kill regulations, additional strategies such as incentivized harvest can be used to enhance population suppression and limit size-selective harvest. Incentivized harvest is widely used for invasive species management (reviewed in Pasko and Goldberg 2014). For example, the harvest of invasive burbot (*Lota lota*) was encouraged through fishing tournaments in Utah, USA (Gardunio et al. 2011), and cash incentives were used to promote lake trout removal in Lake Pend Oreille, Idaho, USA (Dux et al. 2019). However, incentivized harvest can cause anglers to rely on income from invasive species incentives or value the long-term presence of invasive species. As a result, potential newfound appreciation for an invasive species risks encouraging anglers to release invasive fish or spread them elsewhere to maximize future angling opportunities and incentives (Gardunio et al. 2011; Pasko and Goldberg 2014). For example, the idea of incentivized harvest to manage a population of invasive snakehead (*Channa argus*) in New York, USA, was rejected due to such concerns (ANSTF 2014). In summary, if must-kill regulations are enacted, managers should communicate their ecological rationale (supported by evidence) to anglers and emphasize the importance of preventing further spread of invasive species.

Further complicating matters, the assumption that reducing invasive fish populations always mitigates their negative effects may not be universally true. Indeed, invasive species do not always exert monotonic density-impact curves (Jackson et al. 2015; Kornis et al. 2014; Yokomizo et al. 2009). For instance, an experimental study of round gobies suggested that competition pressure on native fishes was higher at moderate goby densities than at higher densities, where interference competition among gobies reduced their impact on native species (Kornis et al. 2014). Furthermore, the relationship between benthic invertebrate abundance and density of invasive stone moroko (*Pseudorasbora parva*) was S-shaped, so benthic invertebrate abundance was generally higher at high densities of stone moroko than at low densities (Jackson et al. 2015). In contrast, the negative effects of invasive common carp in Australia, for example, increased with abundance (Fanson et al. 2024). Examples of invasive species harvest negatively affecting native species are less common than positive effects, but such differences warrant consideration before implementing must-kill regulations, because reducing invasive species population size may not always yield proportional ecological benefits.

Whenever reducing invasive species abundance is a goal, we recommend that stock assessments be conducted prior to the implementation of must-kill regulations. Determining a baseline metric of population size for the target invasive species (e.g., using catch-per-unit-effort; CPUE or another standardized method) prior to the implementation of must-kill regulations is essential for follow-up assessments of must-kill regulation effectiveness in reducing invasive species abundance. For instance, if CPUE declines from baseline levels and is negatively correlated with angler harvest (which could be estimated through creel surveys; Nieman et al. 2021), must-kill regulations may be effective in reducing invasive species population size. Additionally, where feasible, methods such as age-structured population models can be used to identify maximum sustainable yield (MSY), a threshold

to surpass to induce recruitment overfishing. Determining this threshold enables managers to better understand whether angler harvest from must-kill regulations can achieve a required exploitation rate (in addition to other removal efforts; Paukert et al. 2021). For example, an age-structured population model for invasive lionfish (*Pterois* spp.) was used to identify a target yield above population MSY to balance population suppression with socioeconomic benefits in Belize (Bogdanoff et al. 2021).

To navigate these complexities, we developed a decision-making framework to help managers systematically evaluate whether must-kill regulations are appropriate and effective (Figure 1). This framework considers if (1) angling harvest meaningfully contributes to population control, (2) additional removal effort is needed, and (3) unintended consequences could undermine management goals. While this approach is designed for cases where reductions in population size are a primary objective, must-kill regulations may also serve other purposes.

5 | Angler Behaviors and Beliefs

Must-kill regulations have often been discussed as a tool to reduce the spread of invasive fishes by recreational anglers. Specifically, must-kill regulations should reinforce the importance of preventing invasive species dispersal by sending a clear message that illegal stocking will not result in the establishment of new desirable fisheries (Johnson et al. 2009; Rahel and Smith 2018). While this is a plausible outcome, we found no rigorous assessments of whether must-kill regulations actually changed angler beliefs regarding the importance of preventing the spread of invasive species. Therefore, if fisheries managers aim to influence angler awareness and beliefs as a result of must-kill regulations, we recommend that angler beliefs be monitored before and after implementation to assess the effectiveness of regulations in shifting angler beliefs.

Although anglers often support efforts to mitigate the ecological impacts of invasive species (Joffe-Nelson et al. 2023), attitudes toward must-kill regulations vary. Angler opposition to regulations can lead to noncompliance and distrust toward management agencies, particularly when regulations conflict with established recreational practices. For instance, in New Zealand, anglers who fish for invasive common carp and rudd (*Scardinius erythrophthalmus*) generally opposed must-kill mandates because these species were considered a fundamental part of their way of life. As a result, these anglers knowingly and repeatedly violated the law by releasing invasive fish after capture, thereby exacerbating tensions with fisheries managers (Duggan 2015). Similarly, largemouth bass anglers in Japan strongly opposed must-kill regulations, which they viewed as a threat to their sport (Nishizawa et al. 2006). Additionally, anglers in England demonstrated conservation values that favored protecting the popular invasive zander (*Sander lucioperca*), which led to high rates of illegal catch-and-release (Nolan et al. 2019). Last, in the Pacific Northwest USA, managers believed must-kill regulations to be unviable for nonnative smallmouth bass due to angler opposition (Carey et al. 2011). Altogether, these examples illustrate that angler resistance can occur anywhere that anglers significantly benefit (e.g., enjoyment, subsistence, etc.) from fishing for invasive species, which can lead to noncompliance and conflict between anglers and fisheries managers. Accordingly, when must-kill regulations are considered for an invasive fish that is routinely targeted by anglers, we recommend conducting attitudinal surveys to assess angler sentiment prior to implementation.

Inconsistencies in how agencies manage nonnative species can complicate angler perceptions of must-kill regulations. For example, in the Laurentian Great Lakes, nonnative Pacific salmon (*Oncorhynchus* spp.) are stocked and celebrated by natural resource management agencies, while many other nonnative fishes, such as round gobies and common carp, are vilified. This contradiction could contribute to noncompliance and confusion.

Conversely, if an invasive fish being subjected to must-kill regulations is not yet commonly targeted by anglers, must-kill regulations could encourage the development of a new recreational or subsistence fishery. This could yield recreational and economic benefits, particularly in regions with limited angling opportunities or food insecurity. For example, invasive fish can be an important food source that boosts local economies (e.g., nonnative salmonines in Patagonia; Lambertucci and Speziale 2011; Nuñez et al. 2012). However, if anglers value the new fishery, they could resist eradication or suppression and possibly spread the invasive species to create more fisheries (Gardunio et al. 2011; Nuñez et al. 2012). Although we found no reports of must-kill regulations leading to the spread of invasive species, the potential for anglers to intentionally introduce invasive species to create angling opportunities has been made evident by the widespread introduction of popular fishes such as black bass (*Micropterus* spp.), which have become one of the most widely distributed aquatic species in the world, in part driven by illegal angler introductions (Jackson 2002; Long and Seguy 2024). In summary, this tradeoff should be carefully considered when weighing the long-term effectiveness of must-kill regulations.

Other proposed benefits of must-kill regulations include simplifying law enforcement against illegal stocking and demonstrating agency resolve (Johnson et al. 2009). However, strict regulations against possessing live invasive fish (except during brief catch-and-release encounters) provide similar enforcement benefits, and agency resolve can be demonstrated by any evidence-based conservation action. Therefore, we believe that such factors should not be primary considerations in deciding whether to implement must-kill regulations. Nonetheless, must-kill regulations can engage anglers in conservation actions, which can be a rewarding and positive outcome. While angler behaviors and beliefs are crucial for the success of must-kill regulations, the ecological role of invasive species is also important.

6 | Invasive Species Effects

By definition, invasive species have at least some negative impact on ecosystems where they establish. However, some invasive species can also provide benefits, thereby complicating management decisions. For example, the invasion by round gobies in the Laurentian Great Lakes negatively impacted native fish populations through direct competition (Bergstrom and Mensinger 2009) and predation on native fish eggs and mussels (Poos et al. 2010; Steinhart et al. 2004). However, round

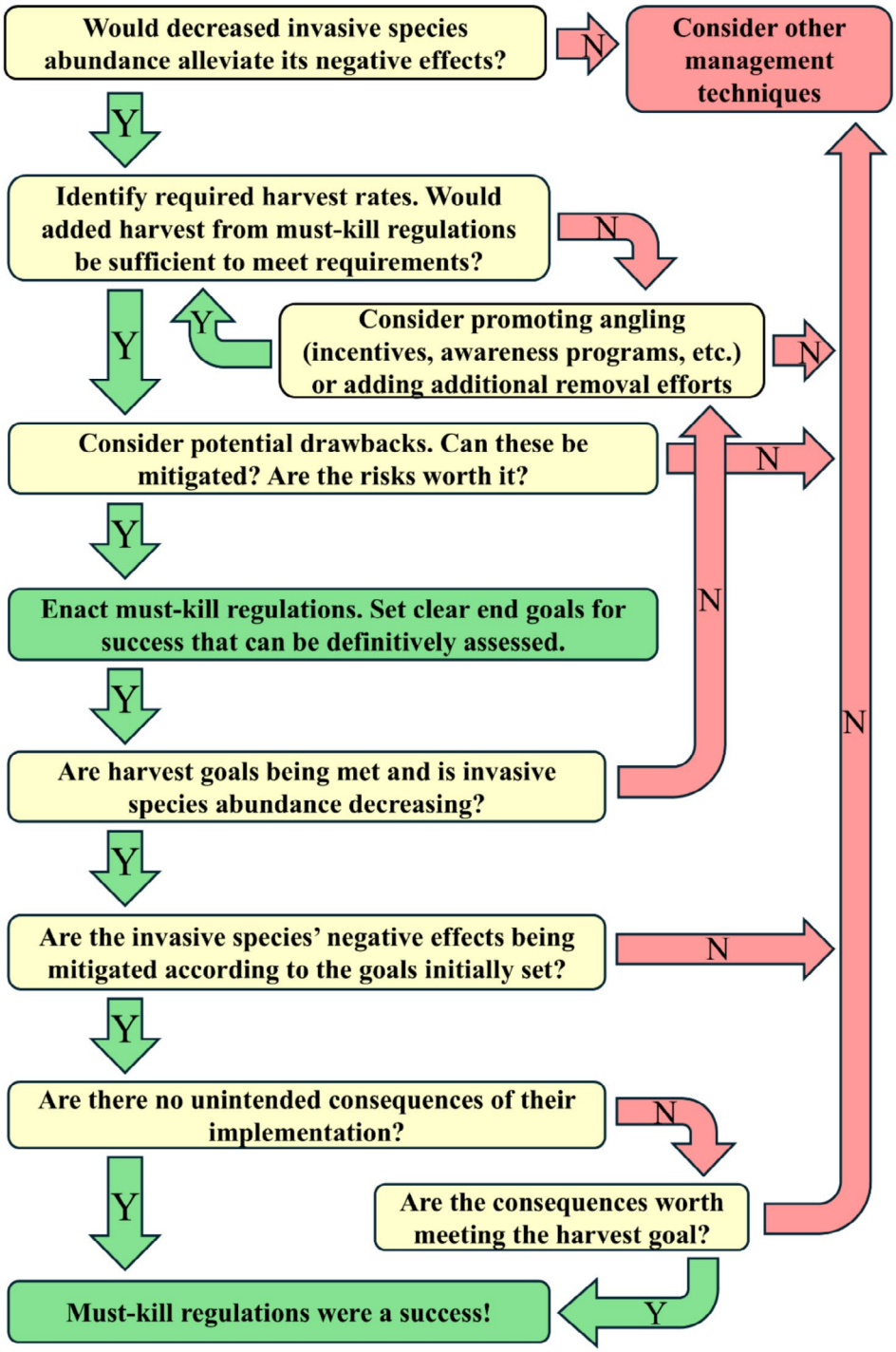

FIGURE 1 | Decision-making framework for evaluating when and when not to implement must-kill angling regulations, and for systematically monitoring the effectiveness of must-kill regulations. Green arrows with a Y indicate the path to follow for a "yes" answer, and red arrows with an N indicate the path to follow for a "no" answer. This flowchart was designed for population control as a primary goal for prospective must-kill regulations.

gobies also contribute ecological benefits by preying on juvenile invasive dreissenid mussels (Barton et al. 2005; Pennuto et al. 2012). Round gobies are also an important food source for native predators such as lake trout (Leonhardt et al. 2020; Taylor et al. 2024), a species of conservation concern in the Great Lakes (Muir et al. 2012). Inclusion of round gobies in lake trout diets also mitigates thiamine (vitamin B_1) deficiency, a major threat to lake trout recovery (Brown et al. 2005), by reducing predation on other prey containing high levels of a thiamine-degrading enzyme (Fitzsimons et al. 2022). Additionally, consumption of round gobies in the Great Lakes has been associated with increased growth of popular fish such as smallmouth bass (Crane and Einhouse 2016).

While the negative effects of invasive species often outweigh benefits, their ecological role should at least be considered

before implementing must-kill regulations. Management decisions should account for both the detrimental and beneficial aspects of invasive species to ensure that must-kill regulations align with broader conservation and socioeconomic goals.

7 | Species Identification

A challenge of must-kill regulations that could undermine intended benefits is the risk of species misidentification. Anglers who mistake invasive species for native species would violate must-kill regulations by releasing them, while anglers who misidentify native species as invasive would kill native fish. This problem is most likely when an invasive species resembles a native species in the same area, but it is less likely when invasive species are easily distinguished from native species. Unfortunately, many invasive species are visually similar to native species, so identification can be difficult for untrained anglers. For example, in North America, round gobies can be challenging to distinguish from native sculpins (*Cottus* spp.). Similarly, invasive carps, such as grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypophthalmichthys molitrix*), which have been introduced to western Europe and northeastern USA, can closely resemble native leuciscids as juveniles. For example, only 2% of anglers fishing on the Missouri River (South Dakota, USA) could distinguish juvenile bigheaded carps (*Hypophthalmichthys* spp.) from native fishes commonly used as live bait (Gerber et al. 2024).

Complicating matters further, some invasive species subjected to must-kill regulations in one area are considered valuable native species in nearby areas. For instance, burbot in Wyoming, USA, are considered invasive and are subjected to must-kill regulations in the Colorado River drainage, but are native and of conservation concern in the Missouri River drainage (Rahel 2016). Thus, even when anglers correctly identify a species, they must also be familiar with local regulations, which can vary over relatively small geographic scales.

Given these challenges, species misidentification must be carefully considered before implementing must-kill regulations. Where invasive species are visually similar to native species, managers should assess the ability of anglers to distinguish invasive species from native species prior to regulation enforcement. If misidentification is common, but must-kill regulations are still necessary, educational initiatives to improve species identification could potentially reduce misidentification (but see Haley et al. 2023). Beyond misidentification challenges, must-kill regulations also raise ethical considerations that warrant careful thought and discussion.

8 | Ethical Considerations

One potential complication of must-kill regulations is the ethical dilemma of when killing fish for conservation is justified. This question is complex and context-dependent (Atchison et al. 2017; Bovenkerk and Braithwaite 2016), as is the ongoing debate over whether fish feel pain and suffering (Diggles et al. 2024; Mason and Lavery 2022). Nonetheless, killing fish for conservation should be done as humanely as possible by using good fish-welfare practices. Ethical euthanasia methods prioritize rapidly rendering fish unconscious, such as percussive stunning or pithing (e.g., using ikijime; Diggles 2016), over prolonged methods like asphyxiation (Robb and Kestin 2002). Because anglers can be important environmental stewards (Shephard et al. 2023), we believe that anglers should adopt and encourage ethical practices for killing fish.

Despite the importance of fish welfare, invasive species are often demonized by education programs. For example, invasive bigheaded carps in the USA have been referred to as "ruthless invaders" and "living pollution" (Natural Resource Defense Council). Militaristic language (e.g., "the war on invasive carp"; Lower and Campbell 2024) is also prominent in invasive species literature (Janovsky and Larson 2019; Larson 2005; Lower and Campbell 2024), despite little support for its effectiveness to increase engagement (Chinn et al. 2024). Demonizing and militaristic language can foster sentiments of disgust and dislike that strip invasive fish of their moral value (Atchison 2019; Brockway 2013). Must-kill regulations for such species can translate into widespread unethical treatment by anglers (Adeli 2022). To illustrate this concern, a strong dislike of bigheaded carp from the Mississippi River Basin (USA) has fueled culling methods that occasionally include killing bigheaded carp with football helmets and baseball bats (Reeves 2019). Additionally, must-kill regulations risk the normalization of anglers killing and discarding species that they personally view as a nuisance, even when those fish are native. For example, native catostomids are often "thrown on the bank" because of a perception that they have negative impacts on gamefish populations, despite playing important roles in freshwater ecosystems (Clancy et al. 2025).

To mitigate these concerns, fisheries management agencies and stakeholders should avoid using language that demonizes invasive species, while still conveying the importance of preventing their spread. Providing clear guidelines for humane euthanasia of invasive fish could ensure that anglers uphold ethical practices while complying with must-kill regulations. Beyond ethical considerations regarding fish welfare, must-kill regulations risk creating inequities for some anglers.

9 | Equitable Considerations for Anglers

Must-kill regulations can force anglers to choose between violating their moral values and risking prosecution and scrutiny for noncompliance (Duggan 2015). This ethical dilemma can limit the enjoyment and accessibility of certain anglers. Even in regions where releasing invasive fish is discouraged but not illegal, such as common carp in New South Wales, Australia, anglers with a strong ethic against killing fish feel restricted in where they can fish to avoid scrutiny from those who believe all carp should be killed. As a result, these individuals may limit their fishing, thereby reducing recreational opportunities, particularly where alternative fisheries are inaccessible (Atchison et al. 2017). In Japan, resistance to killing invasive fish is so strong among recreational anglers that the enforcement of must-kill regulations has been proposed as an effective ban on recreational fishing altogether (Nishizawa et al. 2006). Because

cultural backgrounds can affect the willingness of anglers to harvest or release their catch (Arlinghaus, Cooke, Lyman, et al. 2007), ever-increasing cultural diversity in many areas can further complicate this issue to potentially polarize anglers with differing perspectives. Overall, must-kill angling regulations should be implemented with caution, particularly where anglers appreciate the invasive species in question. Encouraging unlimited harvest of an invasive species, rather than mandating it (such as for northern pike in Nevada, USA; NDOW 2025), could mitigate these concerns. Ensuring that management strategies consider recreational impacts on diverse angler groups may help prevent unintended social consequences.

Globally, the ethics of recreational fishing have come under increasing scrutiny (Arlinghaus, Cooke, Schwab, and Cowx 2007; Cooke and Sneddon 2007; Huntingford et al. 2006), leading to limitations or outright bans against catch-and-release angling in Colombia, Germany, and Switzerland (Arlinghaus 2007; Arlinghaus et al. 2012; Lozada Gomez 2023). As global economic development progresses, public concern for animal welfare may also grow to potentially cause increased opposition to recreational angling over time (Arlinghaus et al. 2012). However, in many developed countries, recreational angling remains widely accepted (Arlinghaus et al. 2021) and provides numerous socioeconomic and conservation benefits (Arlinghaus and Cooke 2009; Cooke et al. 2015, 2016). For those seeking to sustain recreational fisheries, maintaining a positive public perception of recreational anglers is crucial. To the general public, observing anglers killing and discarding fish, regardless of whether this practice is mandated by must-kill regulations, can be unsettling. Such incidents may create the impression that anglers are cruel or wasteful, which could reduce public support for recreational angling. These concerns are particularly relevant in areas where interactions between anglers and nonanglers are frequent. To mitigate these concerns, fisheries managers could consider public education initiatives to clarify the rationale behind must-kill regulations and promote ethical handling and disposal of invasive fish. Further, improper disposal of carcasses, such as leaving them to decompose on a bank, could exacerbate negative public perceptions and impair angler enjoyment. Encouragement of proper disposal, by sinking carcasses or having designated disposal areas, could mitigate these concerns. When possible, encouraging the consumption of euthanized invasive species, rather than disposal of whole carcasses, may also reduce negative perceptions.

10 | Conclusion

Must-kill angling regulations can be a valuable tool for managing invasive fish, but their effectiveness and consequences are context-dependent. While must-kill regulations may provide benefits such as population control, empirical evidence of these benefits is limited. Accordingly, where must-kill regulations are necessary, we urge fisheries managers to set clear and testable goals that can be assessed using pre- and post-implementation monitoring to build evidence in support of this management strategy. Evaluating the efficacy of regulations can be costly, but the numerous potential drawbacks of must-kill regulations emphasize the importance of assessing regulatory success. Potential drawbacks, such as angler opposition or ethical concerns, can outweigh the benefits of must-kill regulations. Simultaneously mitigating every possible drawback may not be feasible, but fisheries managers could minimize unintended consequences by prioritizing concerns that are most likely to undermine the success of must-kill regulations in a given context. For instance, where species misidentification is likely, education initiatives for recognizing invasive species could be prioritized. Ultimately, must-kill regulations may be a beneficial management strategy for invasive fish, but their effectiveness should not be a blind assumption, and their multiple potential drawbacks should be evaluated and mitigated carefully.

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest Statement

The authors declare no conflicts of interest apart from the authors being avid anglers.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Global summary of must-kill regulations for invasive fish management.