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We Can Better Manage Ecosystems by Connecting Solutions to Constraints: Learning from Wetland Plant Invasions

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Wetlands provide critical wildlife habitat, improve water quality, and mitigate the impacts of floods, droughts, and climate change. Yet, they are drained, filled, dredged, and otherwise altered by humans, all of which contribute to their high susceptibility to plant invasions. Given the societal significance of wetlands and the disproportionately large amount of time and money spent controlling invaders in remaining wetlands, a fundamental shift must occur in how we approach restoration of plant-invaded wetlands. The need for more research is often used as an excuse for a lack of progress in invader management but, in fact, constraints to invader management are spread across the science, management, and stakeholder engagement domains. At their intersection are "implementation gap" constraints where the monumental efforts required to bridge the gap among scientists, managers, and community stakeholders are often unassigned, unrewarded, and underestimated. Here we synthesize and present a portfolio of broad *structured approaches* and *specific actions* that can be used to advance restoration of plant-invaded wetlands in a diversity of contexts immediately and over the long-term, linking these solutions to the *constraints* they best address. These solutions can be used by individual managers to chart a path forward when they are daunted by potentially needing to pivot from more familiar management actions to increase efficiency and efficacy in attaining restoration goals. In more complex collaborations with multiple actors, the shared vocabulary presented here for considering and selecting the most appropriate solution will be essential. Of course, every management context is unique (i.e., different constraints are at play) so we advocate that involved parties consider a range of potential solutions, rather than either assuming any single solution to be universally optimal or relying on a solution simply because it is familiar and feasible. Moving rapidly to optimally effective invasive plant management in wetlands may not be realistic, but making steady, incremental progress by implementing appropriate solutions based on clearly identified constraints will be critical to eventually attaining wetland restoration goals.

Keywords: knowledge co-production, adaptive management, adaptive co-management, implementation gap, community stakeholders, uncertainty, use-inspired research

INTRODUCTION

Wetlands support a disproportionate share of ecosystem services relative to their surface area (Duarte et al., 2013; Kingsford et al., 2016). The loss of over 50–70% of the world's wetlands and their associated ecosystem services (Davidson, 2014; Kingsford et al., 2016) provides a strong justification for improved wetland protection policies, management, and restoration (Maltby and Acreman, 2011; Endter-Wada et al., 2020). Nonetheless, wetlands remain among the most threatened ecosystems due to the persistent perception of wetlands as wastelands (Vileisis, 1999; Gardner, 2012) and the cumulative impact of stresses such as water extraction, pollution, and climate change (Vörösmarty et al., 2000; Green et al., 2017; Wurtsbaugh et al., 2017). Wetlands are especially vulnerable to threats from invasive species due to site and landscape characteristics that result in the accumulation of nutrients, sediment, contaminants, and invader propagules (Zedler and Kercher, 2004). The significance of wetland plant invasions was widely acknowledged by the turn of the 21st century (Galatowitsch et al., 1999; Zedler and Kercher, 2005) and although their impacts on ecosystem services are not entirely clear and require accurate assessment (Hershner and Havens, 2008; Eviner et al., 2012), invasions can have profound consequences for social-ecological systems and warrant major concern globally (Shackleton et al., 2018; Lázaro-Lobo and Ervin, 2021). Unfortunately, much work remains to improve wetland invader management. Recent ambitious goals for restoration globally (including the UN Decade on Ecosystem Restoration, Eisele and Hwang, 2019), of which invader management is a large part, heighten the urgency of this mission (D'Antonio, 2016; Weidlich et al., 2020).

For wetland and non-wetland systems alike, constraints to effective invasive species management are social *and* ecological (Cortina-Segarra et al., 2021). Such constraints may especially hinder management of plant invasions in *wetlands* because of their unique landscape distribution and hydrological niche. The strong hydrological, chemical, and biological connections between wetlands across broad regions (Alexander et al., 2018; Leibowitz et al., 2018) means that management should be landscape scale to be effective (Matthews et al., 2009a; Epanchin-Niell and Wilen, 2012). Additionally, because wetlands are transitional between aquatic and terrestrial habitats, subject to shifting boundaries with dynamic water levels, and can be impacted by anthropogenic activities in distant parts of the watershed (Zedler et al., 2012), wetland protection often falls under multiple jurisdictions, complicating coordination (Dudgeon et al., 2006; Endter-Wada et al., 2020).

Although successful invasive plant management is often limited by insufficient funding, the funding gap is also exacerbated for wetlands, due to an underestimation of the problem's urgency and complexity as well as the costliness of successful management (Galatowitsch and Richardson, 2005; Kettenring and Tarsa, 2020). In wetland systems, costs are high because many invaders are clonal, perennial species with extensive propagule banks requiring long-term management to control re-invasion or secondary invasions (Adams and Galatowitsch, 2006; Pearson et al., 2016). Also, in wetlands denuded from aggressive invader control, ecosystem recovery typically requires revegetation and long term management, both of which are resource intensive (Rinella et al., 2009; Kettenring and Adams, 2011; Galatowitsch and Bohnen, 2020).

Efforts to manage invasions and restore ecosystems commonly fall far short of restoration goals (Kettenring and Adams, 2011; Prior et al., 2018). A forward-thinking and holistic approach requires diagnosing the most relevant constraints, and selecting solutions that best address those while leveraging social-ecological connections (Crowley et al., 2017; Shackleton et al., 2019c). In seeking solutions, some have highlighted overall structured approaches, including those focused on treating the underlying ecological cause of invasion (Sheley and Smith, 2012) or combining iterative experiments with actual restoration to enhance learning (Zedler and Callaway, 2003). Other solutions to improve invader management include distinct specific actions, such as monitoring native plant gains along with invader reductions for a true evaluation of outcomes (Kettenring and Adams, 2011) and improving research by engaging in dialogue with practitioners (Funk et al., 2020). Despite the well-designed solutions presented by these and other authors, little guidance exists to link solutions to relevant constraints or compare different recommendations, making it difficult to identify optimal solutions for a particular invasion context. Without clearly articulating when specific solutions are most appropriate, improvements to invader management will be limited. Here we provide a "state-of-the-art review" (Grant and Booth, 2009) aiming for a comprehensive search of current literature to assess the state of knowledge and set priorities for future investigation and research. We also drew from our combined 80 years of experience across several continents, collaborations with colleagues in similar research areas, and discussions surrounding a conference symposium (Kettenring et al., 2019). Our objective was to synthesize many perspectives to detail both broad and specific steps for improving management of plant-invaded wetlands and link them to the constraints they address. To do so, our state-of-the-art review answers two questions:

1) what are the constraints to restoring plant-invaded wetlands, and
2) what are solutions to improve restoration of invaded wetlands?

Although our emphasis throughout the manuscript is on invasive plants in wetlands, many of the constraints we identify and recommended solutions to overcome those constraints will apply to restoration of other invaded ecosystems, particularly other habitats such as those that are degraded and, therefore, highly invasive-prone (Vilà et al., 2007; Chytrý et al., 2008).

CONSTRAINTS TO THE MANAGEMENT OF WETLAND PLANT INVASIONS

Social, economic, and institutional constraints often limit successful invasive plant management, even when the ecology

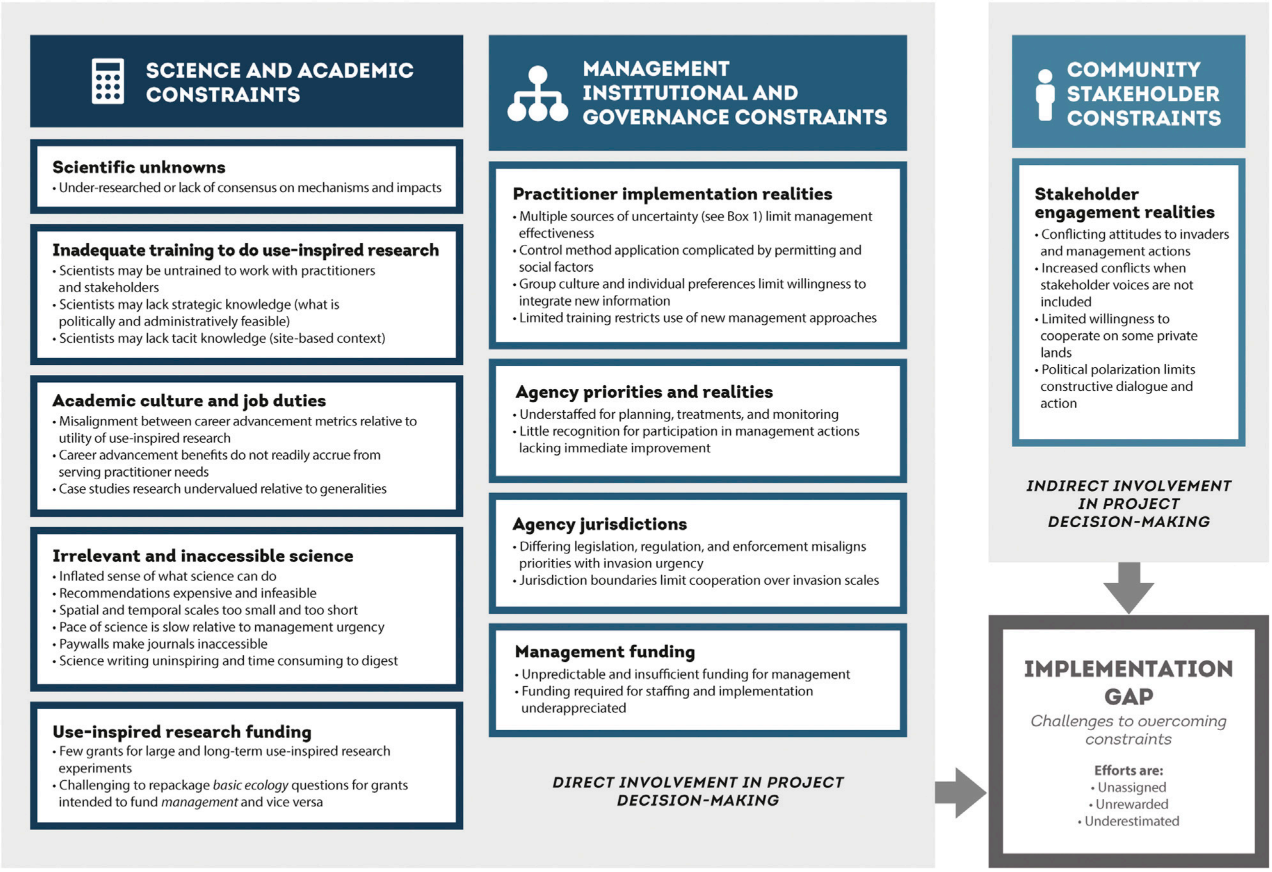

FIGURE 1 | Constraints to the management of wetland plant invasions are broad and span ecological and social realms. Science constraints result from the challenges of doing management-relevant science in academic and research institutions. Management constraints arise from institutional, governance, and financial restrictions that practitioners experience that limit effective invader management. Community stakeholder constraints come from potential conflicts with members of the broader community (who are impacted by or interested in wetland invaders) that may limit effective invader management.

of a particular invader is well understood (Cortina-Segarra et al., 2021). Although the critical limitations to management vary from case to case, several recurring constraints are central (**Figure 1**). Researchers experience myriad *Science and Academic Constraints* to the generation of new knowledge required to improve management (Cvitanovic et al., 2016; Funk et al., 2020). Practitioners charged with implementing management strategies confront challenges linked to *Management Institutional and Governance Constraints* (Walsh et al., 2019), and *Community Stakeholder Constraints* limit inertia to overcome any other constraints. Limits to "bridging the gap" between science, management and stakeholders reflect the fact that the actions needed to do so are often unassigned, unrewarded, and underestimated.

Science and Academic Constraints

Use-inspired research (sensu Stokes, 2011) that simultaneously advances fundamental knowledge of invasion ecology while providing solutions for management is (slowly) gaining traction and respect in academia (Lubchenco, 1998; Lubchenco and Rapley, 2020). Yet, many barriers within academic and research institutions limit the development, relevance, and application of wetland invader research. In this section, we explore constraints to optimal contributions of science to practice. These constraints largely apply to those working in ecology and invasion biology; there are unique exceptions to many of these constraints, including Cooperative Extension faculty at land-grant institutions in the US that routinely develop research products for interested parties (see *Align academic reward systems to prioritize practitioners needs* under suggested *Specific Actions*).

Scientific Unknowns

In many cases, the joint importance of site- and invader-specific characteristics for wetland invasion dynamics means that determining the optimal management strategy is challenging, and ecological research is often lacking. Landscape degradation and environmental variability, both within and among sites, often limits the use of a general strategy and reduces management success. Invader characteristics also often hinder efforts, for instance by exhibiting intraspecific variation and rapid evolution, which limits the use of a general, static approach.

BOX 1 | The ability of managers to effectively control an invader is limited by four sources of uncertainty. Clear identification of the most relevant source of uncertainty should guide the choice of structured approaches and specific actions, since not all efficiently resolve all uncertainties (Walters, 1986 alternative system for naming uncertainty is related to these categories as indicated with footnotes).

Scientific unknowns[a]: Using science to identify effective control strategies can be surprisingly difficult because species may be understudied or research may not agree on a recommendation for best practice, resulting in *scientific unknowns* or *structural/process uncertainty* (Hulme, 2014). Without research, there cannot be evidence-based decisions regarding management. For better researched species, controversy and contradiction are major contributions to the lack of application of science into management (Bertuol-Garcia et al., 2018a). Because resolution of scientific unknowns requires experimentation, research-oriented approaches best resolve this source of uncertainty.

Example: A control treatment may be considered because it can effectively reduce an invader and, therefore, is assumed to promote native wetland plant establishment. However, if that invader has a yet-undiscovered legacy effect (invader modification of the environment) that limits post-control native plant establishment despite its removal (Corbin and D'Antonio, 2012) the effectiveness of the approach in restoring the invaded wetland would be overestimated. In another example, conflicting guidance can be found in the literature on something as substantial as the appropriateness of actively planting or seeding following an invasion (Galatowitsch, 2012 and citations therein).

Environmental variation[b]: The influence of stochastic or unexpected *environmental variation* on invasive plant management outcomes is often unrecognized but can clearly alter the predicted outcomes of treatments such that they might promote the wetland invader. This variability may be temporal, as in year-to-year climatic differences or spatial, as in site-to-site differences (Stuble et al., 2017). When management outcomes are inconsistently effective, it can be difficult to identify and routinely implement the best course of action. Note that for uncertainty about the influence of environmental variation on management actions, such stochasticity cannot be resolved entirely, but it can be incorporated into models and repeated effort approaches.

Example: Since seeding native species is predicted to result in suppression of invaders, revegetation is prioritized. However, extremes in precipitation or temperature may result in limited establishment of native species from seed or reduced competitive ability of newly establishing natives so they do not suppress the invader as expected (Kettenring and Tarsa, 2020).

Partial observability: Monitoring is often used to inform treatment plans, but *partial observability* of populations and ecological and genetic factors mean that monitoring data may not accurately represent the state of the system. These issues typically result from imperfect detection (Kéry et al., 2009), or monitoring plans that do not accurately represent the system (e.g., sample size is too small; plot placement is such that individuals escape detection; response variables are inappropriate), but they can also be associated with improper implementation of monitoring protocols and data that do not provide appropriate information to inform decision making (e.g. poor data quality; measurements that are unable to capture critical ecosystem drivers). Uncertainty associated with the ability of the data to accurately represent resource and management outcomes cannot be resolved by any approach, but can be better understood with repeat observations over time (Williams and Brown, 2016).

Example: Observers collecting monitoring data following *Phalaris arundinacea* removal observe and report 100% cover of native species, categorizing the wetland as "invader free." However, because the monitoring protocol did not require close soil-surface level observations, newly emerged invader seedlings below the canopy of native species go undetected. The wetland is inaccurately represented as dominated by native species, triggering the mistake of deciding not to further manage.

Partial controllability[c]: Fourth and finally, *partial controllability* of management actions implemented means that preferred management actions may not be implemented due to unanticipated events such as inclement weather, labor shortages, or funding and logistical challenges, which can lead to a mismatch between expected and actual planned actions (Moore et al., 2011). Unanticipated logistic challenges to treatment implementation can be reduced with manager-centered approaches.

Example: A graminicide experimentally demonstrated to result in high mortality of an invader is selected as a management action. However, the graminicide is not labeled for aquatic use. Therefore, when unanticipated flooded conditions prevent application of the graminicide, the treatment cannot be implemented and is thus ineffective in reducing the wetland invader in this scenario. Without acknowledging this limitation, the effectiveness of the treatment is overestimated.

[a]Imperfect knowledge is reduced through research. Supported by purposefully collected information, multiple hypothesis testing, statistically designed experimentation and technical modelling

[b]Unpredictability is inherent variability and co-evolution of complex systems (e.g., year to year climate variation; changes in herbicide laws). Supported by observations chosen without considering provision of decision-making information, monitors response to single treatment. Unpredictability cannot be reduced but can be incorporated into models.

[c]Incomplete knowledge is reduced through participatory processes and multiple perspectives are used to construct full system understanding (Walters, 1986).

Their substantial propagule banks commonly promote re-invasion and spread, and for many problematic species, modification of the environment (legacy effects) limits native recovery. Yet in some scenarios, wetland plant invaders may offer ecosystem services (Potgieter et al., 2017) and the net effect of removal requires careful assessment (Hulme et al., 2013; Milanović et al., 2020). For a more complete discussion of constraints associated with wetlands and wetland plants, see Gallardo et al. (2016) and Pysek et al. (2012).

Inadequate Training to Do Use-Inspired Research

Scientists May Be Untrained to Work With Practitioners and Stakeholders

The rigorous research training that many scientists receive through academia serves them well for the "doing of science" (Milanović et al., 2020) but not its implementation. Many scientists are untrained in conducting research that informs basic invasion ecology principles while also considering how managers can *use* the science, i.e., "actionable science", "demand-driven science", and "use-inspired research" (Sarewitz and Pielke, 2007; Palmer, 2009). Additionally, scientific training does not necessarily involve learning how to work effectively with practitioners and how they differ from other stakeholders and research end-users (Hulme, 2014). This training includes learning to identify practitioner stakeholders, build collaborations, and invest the time to establish critical relationships (Knight et al., 2011; Caudron et al., 2012).

Scientists May Lack Strategic Knowledge (what Is Politically and Administratively Feasible)

Scientists are intensively trained to understand uncertainties and nuances in ecology yet often not able to provide the "decisive statements" needed to make management decisions due to a reluctance to prescribe without a very high degree of certainty (McAninch and Strayer, 1989; Lach et al., 2003; Bayliss et al., 2013). This deficiency may also be because scientists lack depth in "strategic knowledge", or awareness of what is feasible based on practitioner organizations' budgets, administration, structure, and politics (Cabin, 2011), leaving them unable to effectively identify usable management solutions (Lach et al., 2003; Sunderland et al., 2009) and acceptable levels of uncertainty (*scientific unknowns*, **Box 1**) in outcomes of recommended actions.

Scientists May Lack Tacit Knowledge (Site-Based Context)

Biological invasions and their management are driven by site conditions and landscape context. Practitioners develop such "tacit knowledge" (i.e., knowledge that is "intuitive, hard to define [and] largely experience based") through years of working on and observing their wetlands and, therefore, have a deep sense of how context might impact management (Boiral, 2002; Hulme, 2014; Sarat et al., 2017). Yet, tacit knowledge is rarely acknowledged, quantified, validated, synthesized, nor well-integrated to improve management (Martin et al., 2012; Drescher et al., 2013). Despite its importance, scientists only have the opportunity to cultivate this place-based knowledge if their research is similarly tied to particular wetlands they observe over time (Schohr et al., 2019).

Academic Culture and Job Duties

Misalignment Between Career Advancement Metrics Relative to Utility of Use-Inspired Research

In academia, a fundamental mismatch exists between the culture, job duties, and career advancement metrics relative to practitioner needs (Caudron et al., 2012). Research-intensive institutions emphasize grant funding and peer-reviewed publication metrics (e.g., journal impact factors and citation rates), and more prestige is associated with funding that prioritizes basic research (Cabin, 2007b). Furthermore, in ecological disciplines, journals that publish applied and use-inspired research are not as highly ranked and considered less prestigious relative to journals publishing basic work (Whitmer et al., 2010). There is, undoubtedly, a great need for basic research, and managers themselves value basic science (Palmer, 2009; Esler et al., 2010; Hulme, 2014). Yet, for academic career advancement in ecology, the importance of metrics that undervalue use-inspired research and stakeholder engagement limits environmentally and socio-economically relevant work (Dettman and Mabry, 2008; Whitmer et al., 2010; Caudron et al., 2012).

Career Advancement Benefits Do Not Readily Accrue From Serving Practitioner Needs

Researchers focusing on practical management solutions invest large amounts of time and money to develop meaningful practitioner-scientist collaborations (Caudron et al., 2012). Unfortunately, use-inspired research outcomes may be messy (e.g., due to inconsistent application of management actions associated with *partial controllability*), or uninterpretable (e.g., due to environmental variation) (**Box 1**), and therefore, potentially unpublishable. This disincentivizes scientist involvement in most career advancement systems, therefore also deterring them from trying to serve manager needs (Dettman and Mabry, 2008).

Case Studies Research Undervalued Relative to Generalities

High utility studies for improving management are practical, and in response to manager's needs (Sarewitz and Pielke, 2007), often requiring a case study approach resulting in site-specific management recommendations. This approach conflicts with traditional priorities in science that favor novel research resulting in the development of general principles with global relevance (Whitmer et al., 2010; Caudron et al., 2012; Hulme, 2014). However, undervaluing case study research unfortunately diminishes the utility of science in areas where advances are urgently needed, such as wetland plant invasions (Whitmer et al., 2010).

Irrelevant and Inaccessible Science

Inflated Sense of What Science can Do

Academic publications and proposals often emphasize novelty, generalities, and exciting packaging. The science produced or proposed may be intellectually stimulating but "esoteric," leading to a disconnect between what scientists think their research means for management relative to what practitioners actually need. As a result, research may be oversold with minimal relevance to practitioners and invasive species problem-solving (Robison et al., 2010; Bayliss et al., 2013; Bertuol-Garcia et al., 2018a). Even the most relevant information from new ecological research may not factor into a practitioner's decision making (Pullin et al., 2004; Pullin and Knight, 2005; Runge et al., 2011) because other more restricting factors such as budgets, feasibility, logistics, politics, and social constraints override research needs (Bertuol-Garcia et al., 2018a; Schohr et al., 2019).

Recommendations Expensive and Infeasible

Invasive plant research is rarely designed to provide solutions for practitioners (Hulme, 2014; Leblanc and Lavoie, 2017). Even research that evaluates control techniques focuses primarily on ecological responses and rarely considers human aspects to decision making (Kettenring and Adams, 2011; Hulme, 2014; Matzek et al., 2015). For instance, although late summer or early fall is optimal timing for systemic herbicide application efficacy to control many common wetland invaders (Adams and Galatowitsch, 2006; Rohal et al., 2019a; Bansal et al., 2019), treatment application timing is often governed by seasonal labor availability, which peaks earlier in the summer. Studies are needed that evaluate a range of treatment and management options to allow practitioners to weigh trade-offs in effectiveness vs. other constraints (e.g., Jardine and Sanchirico, 2018; Matthews et al., 2020). From an ecological standpoint, the most successful treatment (e.g., hand-pulling individual plants) may be entirely impractical for practitioners due to costs and logistics (Kettenring and Adams, 2011) or for more complex reasons, such as whether treatments are prohibited by the current government (Gibbons et al., 2008).

Spatial and Temporal Scales Too Small and Too Short

Invasive species management occurs over broad spatial and temporal scales, sometimes with highly variable weather and environmental conditions (Stuble et al., 2017; Hardegree et al., 2018). Yet, wetland scientists who seek to develop robust prescriptions for invasive species management often must take a reductionist research approach. Small plots and short time scales for treatment implementation and monitoring are a result of the logistical, institutional, and economic constraints scientists face (Kettenring and Adams, 2011; Anderson, 2014; Matzek et al., 2015). Unfortunately, effective invader treatments based on such experiments rarely translate to restoration success across the large areas where management occurs (Baskerville, 1997; D'Antonio et al., 2004; Erskine Ogden and Rejmánek, 2005) and across highly variable ecological and socio-economic contexts (D'Antonio et al., 2004; Pauchard and Shea, 2006; Esler et al., 2010).

Pace of Science Is Slow Relative to Management Urgency

Practitioners seek rapid solutions to urgent invasive species management concerns (McAninch and Strayer, 1989; Cabin, 2011). This need conflicts with the usually incremental pace at which science proceeds and the subsequent journal publications become available (Kareiva et al., 2002; O'Donnell et al., 2010). For managers to incorporate new knowledge, it needs to reach managers rapidly; in reality managers must often act before such rigorous science can be completed (Dettman and Mabry, 2008).

Paywalls Make Journals Inaccessible

A common constraint to effective invader management is that although practitioners value peer-reviewed literature (Matzek et al., 2014), they do not routinely consult it to inform urgent decisions (Hulme, 2014; Matzek et al., 2014, 2015; but see Seavy and Howell, 2010). In addition to the reasons for this noted above, paywalls often make journal articles inaccessible as agencies typically cannot afford expensive journal subscriptions (Pullin and Knight, 2005; Bayliss et al., 2013). Despite the advent of open-source journals, which provide free access to select publications, both paywalls and the need for rapid action leads to reliance on other sources of information.

Science Writing Uninspiring and Time Consuming to Digest

Even when managers can access articles in peer-reviewed journals, the ability to understand, interpret, and synthesize new research is limited by dry, dense science writing that can be "unintelligible" and "incomprehensible" (Esler et al., 2010; Bayliss et al., 2013; Cook et al., 2013). Furthermore, the most relevant insights for any given problem may be scattered throughout the peer-reviewed and grey literature, requiring a significant time investment to identify and synthesize relevant information (Pullin and Knight, 2005; Bertuol-Garcia et al., 2018a). Managers cite time constraints as a significant barrier to incorporating science into their decision making (Renz et al., 2009), thus it is not surprising that managers turn to research summaries, peer advice, and workshops instead of journal articles to inform management decisions (Robison et al., 2010; Seavy and Howell, 2010; Bayliss et al., 2013; Walsh et al., 2015).

Use-Inspired Research Funding

Sustaining use-inspired research experiments at management-relevant scales requires significant financial investments that are rarely achieved (Lemieux et al., 2018). Larger sources of research funding (e.g., NSF, NSERC, NERC) could support such efforts, potentially even in a way that requires practitioner-scientist collaborations (Arnott et al., 2020). However, these agencies traditionally prioritize novel, basic science that leads to advancing theory rather than practice (Leshner, 2007; Carter et al., 2020). Funding sources geared towards the place-based, practical research managers need are usually smaller and shorter-term (e.g., a single state budget fiscal year) (Carter et al., 2020). These smaller grants often have a higher success rate (e.g., 30–70%) than, for example, NSF (~3–20%), and multiple small grants can be pieced together. Yet, this approach is still high-risk for supporting a multi-year experiment that requires long-term personnel commitments yet funding provided in only single year increments.

Management Institutional and Governance Constraints

Social constraints to improving invasive plant management may be more important than ecological constraints (Ntshotsho et al., 2015; Cortina-Segarra et al., 2021), yet their implications are comparatively under-researched (Shackleton et al., 2019c). Here we describe institutional, governance, and policy constraints that often limit the incorporation of science-based approaches to effective invasive wetland plant management and the restoration of invaded wetlands.

Practitioner Implementation Realities

Multiple Sources of Uncertainty Limit Management Effectiveness

Effective management of wetland invaders is challenging, in part because of the multiple sources of uncertainty practitioners face. This uncertainty is magnified when multiple sites are in question, because although it is generally acknowledged that restoration efforts should prioritize wetlands with a higher likelihood of success (e.g. when the surrounding landscape is minimally degraded (National Research Council, 1992; Long et al., 2017)), the factors underlying that likelihood are often unclear. Uncertainty reflects one or more of the following issues: 1) research failing to provide clear recommendations (*scientific unknowns*), 2) treatment effectiveness varying from site to site and season to season (*environmental variation*), 3) good monitoring data lacking to assess management outcomes (*partial observability*), and 4) unanticipated logistics limiting the implementation of preferred management actions (*partial controllability*; **Box 1**).

Control Method Application Complicated by Permitting and Social Factors

Practitioners commonly encounter operational barriers to implementing science-based invasive management practices due to logistical and sociological concerns. For instance, permitting issues for prescribed fire, lack of access to animals for grazing, and limited water availability for hydroseeding can make recommended practices unfeasible (Schohr et al., 2019). Conflicting attitudes from various stakeholders may also arise when the invasive nature of a plant is less of a concern to some, e.g., shoreline property holders who prefer sparse aquatic vegetation versus recreational anglers who prefer densely vegetated native habitat (McDuff et al., 2008).

Group Culture and Individual Preferences Limit Willingness to Integrate New Information

Despite the potential for research discoveries to inform management of wetland plant invaders, barriers related to natural resource management agency culture can prevent discoveries from being incorporated into decision-making. Biodiversity losses due to invasion instill urgency in wetland managers, increasing reliance on the most immediately available information such as internal experiential knowledge (Pullin et al., 2004; Bayliss et al., 2012; Matzek et al., 2014; Lemieux et al., 2018). Although this approach can be highly effective (Drescher et al., 2013), ignoring new information sources where expert knowledge is faulty can be problematic (Walsh et al., 2015). Bureaucratic resistance to change can also limit the incorporation of new knowledge (Sarewitz and Pielke, 2007), simply because day-to-day decision making processes rarely prioritize searching literature for new evidence (Cook et al., 2013; Walsh et al., 2019). Practitioners themselves are not reluctant to engage in research-related management (Renz et al., 2009), so perhaps this barrier to adoption of novel science-based ideas is driven instead by inertia in agency operations.

Limited Training Restricts Use of New Management Approaches

Training deficiencies among managers may also limit effective use of information provided by researchers (Walsh et al., 2019). For example, the recognition of linkages among wetland complexes has led to the conclusion that wetland plant invasions should be managed on a landscape scale (Matthews et al., 2009b; Rohal et al., 2019a). However, landscape-level management plans are rarely implemented (Trammell et al., 2018), possibly reflecting limited training in landscape ecology among practitioners who are hired for field operations skills, rather than other expertise. Similarly, a lack of botanical expertise often limits the effective management of plant communities, for example when practitioners cannot distinguish desired species from invaders (Jacobson et al., 2006; Kelley et al., 2013). Even addressing these shortcomings may not meet current training needs, as they reflect a larger pattern in universities focusing on skills for recognizing and documenting environmental decline, but comparatively limited emphasis on skills needed to stop or reverse this decline (Knight et al., 2008).

Agency Priorities and Realities

Understaffed for Planning, Treatments, and Monitoring

Demands on practitioner time (e.g., reporting requirements, maintenance) and funding shortages limit resources available for evidence-based planning, management, and post-control monitoring to optimize wetland invader control (Carter et al., 2020). These challenges are compounded by the severe understaffing of many conservation lands. For example, chronic understaffing in the US National Wildlife Refuge System (which manages much of the country's public conservation land) resulted in struggles to implement basic invasive species control (Smiley, 2008). Under such circumstances, managers have few opportunities to integrate science and make management adjustments (Carter et al., 2020) or to conduct follow-up invader control, particularly after project-specific funding periods terminate (Galatowitsch and Bohnen, 2020). Staffing constraints can also limit post-management monitoring, one of the most time-consuming and expensive but necessary activities that practitioners engage in. Sustaining the substantial personnel and capital resources required to effectively monitor can be difficult (Williams and Brown, 2014), especially as the enthusiasm and support for new projects diminishes over time coincident with a shift to routine monitoring and data management (Galatowitsch and Bohnen, 2020).

Little Recognition for Participation in Management Actions Lacking Immediate Improvement

Practitioners may routinely implement trials with management, the results from which improve management over time; however, in-depth experimentation is typically not considered a primary job duty. Although working with scientists to do research can yield high utility recommendations for managing invasive wetland plants, managers are rarely incentivized to do so. For underfunded and understaffed management agencies, increasing operational complexity by adopting new approaches or participating in science-management partnerships may be seen as a drain on already scarce practitioner time (Galatowitsch and Bohnen, 2020). As a result, over-committed individuals and those who work more hours than required may typically be the only practitioners involved in sustained science-research partnerships (Moore et al., 2011).

Agency Jurisdictions

Differing Legislation, Regulation, and Enforcement Misaligns Priorities with Invasion Urgency

Practitioners witnessing the urgent nature of impacts from invasive plants express frustration with the lack of agency agreement regarding management priorities (Tu and Robison, 2013). This disconnect is particularly problematic because institutions responsible for invader control and ecosystem restoration often operate separately (Herrick, 2019) in their own "silos" (Hodgson et al., 2019), as do agencies that manage invasive plants and wetlands (Endter-Wada et al., 2020). In fact, Herrick (2019) identified 30 policies spread across eight federal agencies, despite the fact that states bear primary responsibility for actually managing invasive plants (Environmental Law, 2012). Governance models also vary widely from country to country, from nation-wide oversight in South Africa to a lack of governance surrounding invasive species in many Latin American countries (Speziale et al., 2012). Global cooperation is similarly challenged, given the many different organizations involved in various dimensions of invader management and wetlands (e.g., Ramsar Convention on Wetlands, Convention on Biological Diversity, International Plant Protection Convention, Food and Agriculture Organization of the United Nations).

Jurisdiction Boundaries Limit Cooperation Over Invasion Scales

The effect of regulatory "silos" intensifies for widespread and problematic wetland plants because wetlands are largely public lands spanning many property boundaries (Carter et al., 2020) and are therefore subject to different jurisdictions with separate decision-makers. Land use surrounding invasions can also vary broadly across the range of an invader, resulting in different acceptable actions and reducing the potential for invader control (Epanchin-Niell et al., 2010; Carter et al., 2020; Aslan et al., 2021). Attitudes toward invader control can depend on ownership, e.g. "on my land" versus "on conservation land," as well as on traditions and heritage (Shackleton et al., 2019c). Such attitudes reflect complex factors related to valuation of invader impacts relative to perceived invader benefits (Essl et al., 2017). Invasive species that negatively impact farmland are broadly recognized as high management priorities, but prioritization of invaders that threaten conservation lands may vary from region to region (Shackleton et al., 2019c). Such regional differences translate into differing optimal control strategies across jurisdictions that have their own goals and objectives (Sher et al., 2020), an important but relatively under-studied research topic (Tonini et al., 2017).

Management Funding

Unpredictable and Insufficient Funding for Management

Although the economic benefits are well-described (BenDor et al., 2015a; BenDor et al., 2015b), management and restoration—and the agencies that conduct such work—are typically underfunded to conduct their missions (Smiley, 2008; Perring et al., 2015; Rohr et al., 2018; Cortina-Segarra et al., 2021). For invasive wetland plant management, this funding gap reflects both an underestimation of urgency and the costliness of revegetation remedies (Seabloom and van der Valk, 2003; Galatowitsch and Richardson, 2005; Kettenring and Tarsa, 2020). Compounding these budget shortfalls, managers face considerable budget uncertainty (i.e., *partial controllability*, **Box 1**). General operations budgets that include invasive plant management vary year to year, complicating implementation of multi-year control plans, which are critical for managing invasions and ecosystem recovery (Rinella et al., 2009; Kettenring and Adams, 2011; Pearson et al., 2016).

Funding Required for Staffing and Implementation Underappreciated

Beyond management funding shortfalls, the resources required to incorporate science-based recommendations into management and support needed staff are often lacking (Jacobson et al., 2006; Martin and Blossey, 2013; Tu and Robison, 2013). For example, in a retrospective assessment of *Phalaris arundinacea* management in lowland savannas, project leaders recognized that The Nature Conservancy lacked staff and resources to undertake the complex historical analysis required to meet project goals (Dettman and Mabry, 2008). While a shortage of in-house technical expertise could presumably be filled by external scientists, scientist involvement is not always cost effective, given the funding amounts often necessary to incentivize it. Practitioners, too, face challenges to participate in activities supporting science application to management, which may be difficult to balance against other core agency responsibilities that are already short-staffed (Renz et al., 2009). Such activities may be viewed as high-expense and low-utility by administrators of natural resource management agencies, who may therefore not want to support them (Moore et al., 2011).

Community Stakeholder Constraints

Above we emphasize constraints associated with those formally *involved* with invasive species decision-making, research, and management projects (i.e., "project stakeholders"; Shackleton et al., 2019a). These include granting organizations, project managers, restoration practitioners, land managers, field biologists, researchers, hydrologists, native plant producers, and machine operators (Howell et al., 2012; Shackleton et al., 2019a). However, most projects also have "community stakeholders" who are impacted or interested in invader spread and control (Howell et al., 2012; Shackleton et al., 2019a; Gamborg et al., 2019). These groups include policy makers, local and state agency representatives, support organizations, neighbors, citizen groups, and landowners (Howell et al., 2012; Shackleton et al., 2019a). Community stakeholders are essential for building enthusiasm for, raising awareness about, garnering political support for, raising credibility and legitimacy of, and increasing financial resources for invasive species management (Howell et al., 2012; Shackleton et al., 2019a, 2019b).

However, strong and sometimes opposing opinions about invaders and management actions within the stakeholder community also represent potential constraints to successful invader management (Howell et al., 2012; Shackleton et al., 2019c; Carter et al., 2021; Cortina-Segarra et al., 2021). Some community stakeholders may view a wetland invader in a positive light that conflicts with its negative ecosystem impacts and motivation for management. For instance, *Lythrum salicaria* (purple loosestrife) produces beautiful purple flowers valued by gardeners and beekeepers, yet is an aggressive invader of wetlands. Certain management actions can also be controversial (e.g., herbicide application or prescribed fire), possibly leading to conflict (Howell et al., 2012). Thus, where local stakeholders devalue invasive control relative to perceived invader benefits, successful management may be substantially hindered.

Stakeholder opinions about invaders and their management may depend on stakeholders' economic interests (e.g., recreational vs. extractive land use), knowledge and education, personal value system, sense of place, and politics (Carter et al., 2021). In a globally significant example, South American countries experience "generational amnesia", in which citizens' ignorance of pre-invasion species composition limits concern for invasions and support for national policies protecting natural areas (Speziale et al., 2012) . Stakeholder opinions may also reflect the impacts of an invader on stakeholders (e.g., private landowner vs. policy maker) and on their access to public land (Howell et al., 2012; Head, 2017; Shackleton et al., 2019a, 2019c, 2019d). Increased conflicts arise and progress is limited when community stakeholder voices are not heard and addressed in invasive species decision making, research, and management projects (Head, 2017; Shackleton et al., 2019a, 2019c). Although comparatively less attention has been paid to community stakeholder constraints than science and academic constraints or management, institutional, and governance constraints, we note that community stakeholder constraints override even the most effective efforts to resolve other constraints, and therefore may be considered paramount.

Implementation Gap

Many of the constraints discussed here reflect a lack of routine translation of science to practice, which plagues not only wetland plant invasions but much of conservation (Bertuol-Garcia et al., 2018a). This implementation gap (Knight et al., 2008), also termed the great divide (Anonymous, 2007), the knowledge-action gap (Cook et al., 2013), the science-practice gap (Cabin, 2011), and the knowing-doing gap (Hulme, 2014), summarizes problems that result when managers, scientists, and stakeholders operate in separate domains with fundamental differences that stymie collaborative progress (Anonymous, 2007). Slow progress in overcoming this critical limitation to managing wetland plant invasions, despite the substantial attention drawn to this issue, reflects the fact that the work required to overcome this gap is usually unassigned, unrewarded, and underestimated (**Figure 1**).

Because the practitioner's job is resource management and the academic's job is research, the steps to incorporate research advances into management are often unassigned to either party. Since actionable science and science-based decision-making depends on the commitment of both scientists and decision-makers (Cook et al., 2013), either party could initiate actions to bridge this gap. Yet, performing these activities (e.g. designing and field-testing monitoring schemes, tasks related to on-boarding and retaining long-term participants) requires a profound transformation of the role of both scientists and practitioners (Gonzalo-Turpin et al., 2008).

Actions associated with bridging the gap are also frequently unrewarded. Managers are evaluated by hectares (acres) restored and monitoring tasks and projects completed (Anonymous, 2007), thus they can only participate in research-management partnerships if such work is strongly supported by upper administration (Moore et al., 2011; Cook et al., 2013). Scientists are evaluated by students trained, grant dollars raised, and peer-reviewed papers published, all of which may conflict with efforts to bridge the implementation gap.

Lastly, evidence suggests that the work needed to step into the role between traditional research and typical management is vastly underestimated. Enquist et al. (2017) noted that scientists should devote more time to management-oriented efforts than a conventional research program usually entails, e.g., with involvement continuing beyond the usual conclusion of research. Unfortunately, few researchers detail their efforts to shift from a scientific framework of discovery to an application focus on problems faced (Gonzalo-Turpin et al., 2008). We do know that collaborative efforts require considerable time commitment (Shaw et al., 2010), which can be hard to justify given workloads and incentive structures.

SOLUTIONS: STRUCTURED APPROACHES AND SPECIFIC ACTIONS

Reducing invasive wetland plants and their impacts will require concerted efforts that build on existing institutions using solutions that will vary over time and space (Schelhas et al., 2012). The optimal solution to any particular wetland invasion problem will rarely be clear because, like decision-making in natural resource management generally, these scenarios often involve "wicked problems" which have no obvious solution or solutions that may themselves become subsequent problems (Lach et al., 2003). Here we present solutions for more effective invasive plant management that directly address constraints. Several structured approaches to intentionally help bridge the "implementation gap" have been developed and are best applied at initial stages of an effort (**Figure 2**). Many of these approaches employ specific actions that can also stand alone and be initiated at various stages of a research or management project (**Figure 3**). Armed with knowledge of various solutions and their strengths and weaknesses, researchers and practitioners can identify and implement solutions that are most relevant given constraints inherent to any invasion scenario (**Figure 4**).

Structured Approaches to Improve Management of Wetland Plant Invaders

When scientists and practitioners initiate an effort to improve management of wetland plant invaders, they may take a broad view, seeking one of the possible umbrella "structured approaches" promoted by the literature. The instinct is to seek and apply the optimal structured approach, but no single approach is optimal; rather, choosing the most appropriate approach requires consideration of the various contexts in which such work is initiated. In this section, we describe these approaches, their appropriate context, and challenges and opportunities associated with each approach. Selection of the optimal structured approach should be driven by several contexts for any wetland plant invasion, specifically: 1) the management urgency, which reflects invader impacts and ecosystem threats; 2) the extent of public pressure to act; 3) how much is known about the invader (knowledge gaps); 4) the potential for productive collaborations between scientists and managers; and 5) the extent and longevity of institutional support for management. We note that the higher public pressure and/or institutional support required by most approaches may restrict their application to European, North American, and Australasian countries, e.g. attitudes and corresponding policies in South American countries may be insufficient to support these approaches (Speziale et al., 2012).

In some scenarios, knowledge gaps are small, and there is sufficient knowledge to proceed directly with management. In contrast, when knowledge gaps are large, research should usually

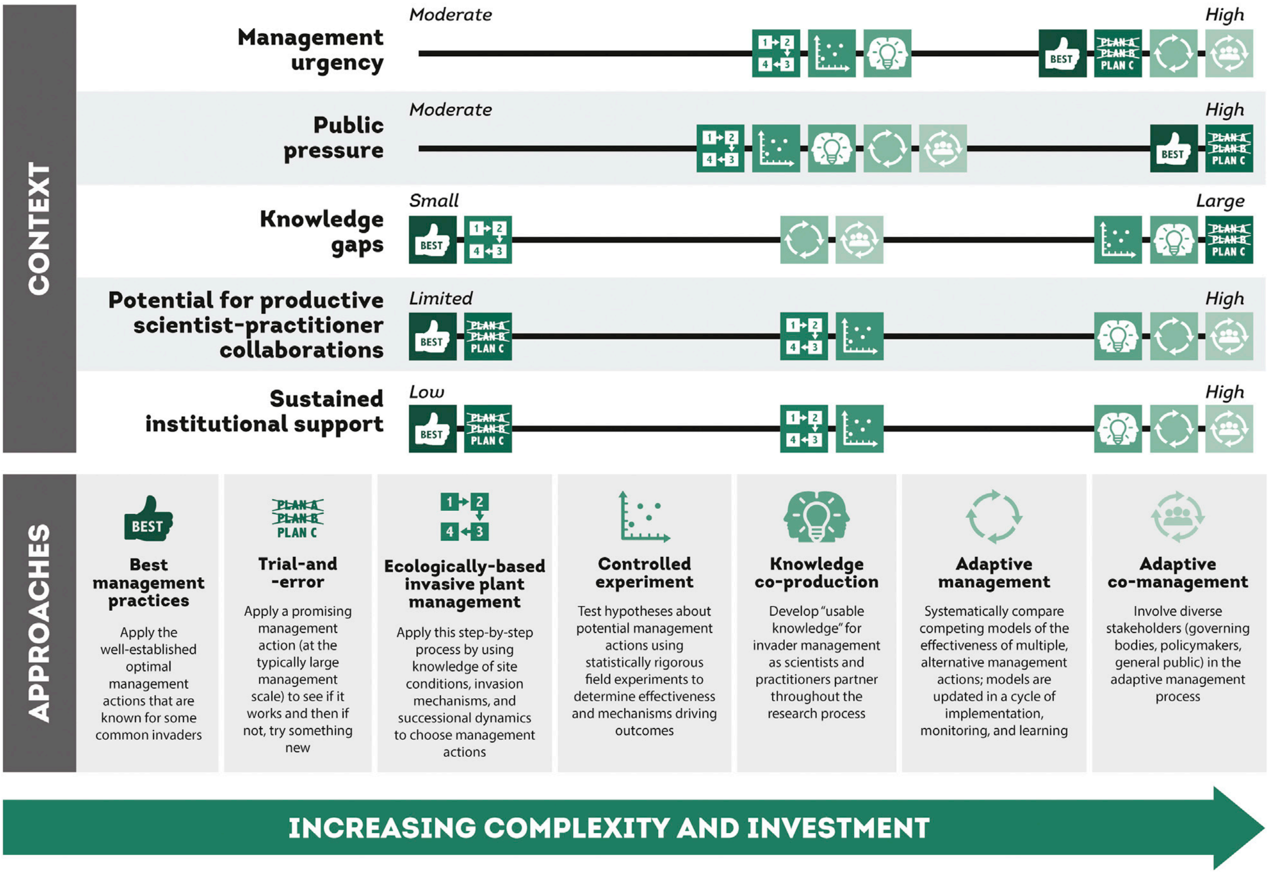

FIGURE 2 | Several structured approaches can be employed to address wetland invasions. These structured approaches reflect the myriad ways that science and management intersect along a continuum of complexity and investment. The choice of which structured approach is appropriate for a given situation depends on context: the urgency for management, the extent of public pressure to control an invader, how much is known about an invader and its management ("knowledge gaps"), the potential for productive scientist-practitioner collaborations, and the likelihood for sustained institutional support. Management urgency is high when impacts to valued resources such as areas for recreation, conservation, or other ecosystem services are known to be considerable. Public pressure is high when the invader is a high-profile species or stakeholders are outspoken (both of which may be unrelated to risk). Knowledge gaps are large when invader mechanisms or successful management approaches are unknown and small when a best management action has been identified by experiments or experience. The potential for productive scientist-manager collaborations is high when there is large uncertainty regarding management outcomes and invader mechanisms; potential is limited when best management practices are widely accepted. Sustained institutional support in the form of financial, personnel, and infrastructure investments is important for all approaches but must be particularly high for the more involved approaches.

precede management actions (i.e., "*ex ante* learning", Dubois et al., 2020). However, when large knowledge gaps occur together with high management urgency, learning may need to happen simultaneously or after-the-fact ("*ex post*" learning, Dubois et al., 2020). Sustained institutional support for any particular scenario may range from well-funded endeavors with long-term (often federal) grants, to a funding portfolio of numerous smaller grants potentially combined from stakeholder partners or involved agencies. The potential for productive scientist-practitioner collaborations is high when the possibility to learn is greatest, so when uncertainty needs to be resolved (the best practice is not known), this is opportune for scientists and managers to actually work together. Structured approaches are also distinct as they may be manager-driven, researcher-driven, or both. Dominant criteria for structured approaches (**Figure 2**), examples of each (**Table 1**) and discussion of considerations unique to each approach is provided below.

Best Management Practices

The best management practices (BMP) approach is optimal for rapid mitigation of invasions by well-researched, commonly managed wetland invaders with well-established management strategies for typical invasion conditions (Gettys et al., 2009). A BMP results from decade(s) of learning from management and often research, as well as formal and informal information sharing among practitioners and researchers, after which many sources of implementation uncertainty have been resolved (*partial controllability*, **Box 1**). BMPs are most appropriate when there is high management urgency and strong public pressure to control the invader, because only when these factors are relaxed is there more flexibility for incorporating learning into the process. Commonly this approach involves herbicide use, perhaps because it is the most frequently examined control method in invasive plant control experiments and often the most effective (Kettenring and Adams, 2011). We note that BMPs should not be

TABLE 1 | For each of the seven Structured Approaches we describe in the text, an example of its implementation from is provided here; examples in peer-reviewed journal articles were prioritized. Wherever possible, these examples are drawn from approaches taken to manage invasive species in wetlands; however, we emphasize that none of these approaches are ecosystem-specific.

Structured Approach	Focal invasive species	Ecosystem	Description
Best Management Practices	hydrilla (*Hydrilla verticillata*)	many regions throughout the US and globally	Decades of research and case studies have revealed that, for hydrilla, a suite of aquatic-approved herbicides is the most appropriate and efficient management option in most cases (True-Meadows et al., 2016; Enloe and Gettys 2019a; Enloe and Gettys 2019b). Note, however, that BMPs may not be static, e.g. recent reports of herbicide-resistant hydrilla populations Enloe and Gettys (2019b) mean that in some areas the "best" practice is being reconsidered and improved.
Trial-And-Error	multiple	tropical dry forests in Hawaii	In these endangered and degraded ecosystems, Cabin (2007b, 2007a) implemented trial-and-error ("intelligent tinkering") for restoration of critical forest species in an on-site, large-scale restoration program. In this urgent management scenario, trial-and-error was preferable to the use of controlled experiments for improving invasive plant management because it did not require untreated control plots that would promote invasive spread and proceeded at a more rapid pace, matching that of management urgency.
Ecologically-Based Invasive Plant Management (EBIPM)	spotted knapweed (*Centaurea maculosa*), sulphur cinquefoil (*Potentilla recta*), cheatgrass (*Bromus tectorum*)	ephemeral wetlands in western US (Montana)	(Sheley et al., 2006; Sheley et al., 2010) began with site-level assessments that revealed key differences among invaded sites in their level of physical disturbance, the extent of remnant native plant communities, overall divergence from restoration targets, and the availability of "safe sites" for native seedling establishment. Site-specific management actions were then developed using varying combinations of drill seeding, irrigation, disking, and soil imprinting to increase soil moisture in response to these differences. Ultimately, the use of EBIPM highlighted site-specific influences on invader abundance and native species establishment, which resulted in improved invasive species management outcomes.
Controlled Experiments	reed canary grass (*Phalaris arundinacea*)	wet meadows in north central US (Minnesota)	Adams and Galatowitsch (2006) used controlled experiments to compare commonly used but under-performing management approaches (spring glyphosate applications, natural recolonization by natives) with alternative treatments (late season glyphosate applications, seeding natives) and untreated controls. Late season herbicide application was more effective than spring herbicide application, and native seeding preempted *P. arundinacea* reinvasion better than natural recolonization. These comparisons permitted a direct assessment of restoration effectiveness gains from adopting novel techniques.
Knowledge Co-Production	phragmites (*Phragmites australis*)	Great Salt Lake wetlands in Western US (Utah)	Researchers initiated collaborations by surveying practitioners regarding their management goals, strategies, and challenges (Rohal et al., 2018). Relevance of the intended research for practitioners was maximized by incorporating practitioner insights and site-based knowledge and by conducting experiments at longer temporal and larger spatial scales than would have been possible without access to management machinery (Cranney, 2016, Rohal et al., 2019a, Rohal et al., 2019b). Management effectiveness was improved because new knowledge and treatment recommendations were incorporated into ongoing management (with enhanced buy-in from practitioners who had seen which treatments were working firsthand). Practitioners also collaborated on Cooperative Extension documents that summarized research findings, ensuring that research results were presented in a manner that was useful for practitioners (Rohal et al., 2016, Duncan et al., 2019).

(Continued on following page)

TABLE 1 | (*Continued*) For each of the seven Structured Approaches we describe in the text, an example of its implementation from is provided here; examples in peer-reviewed journal articles were prioritized. Wherever possible, these examples are drawn from approaches taken to manage invasive species in wetlands; however, we emphasize that none of these approaches are ecosystem-specific.

Structured Approach	Focal invasive species	Ecosystem	Description
Adaptive Management	phragmites (*Phragmites australis*)	Great Lakes region of the US and Canada	Adaptive Management targeting invasive *P. australis* began with a team (including managers, resource specialists, a decision analyst, and a project coordinator) conducting a year-long series of workshops to establish: (1) a management objective (reduce *P. australis*), (2) a monitoring plan (measure *P. australis* presence or absence in sampling plots), (3) potential management actions (different combinations and timing of herbicide application, fire, and mowing), and (4) competing models to explain presence/absence via management actions. Four years post-initiation, 71 participating managers working on 220 sites are enrolled in the program. These managers annually receive recommended actions from the coordinator, carry out these actions, monitor outcomes, and share data. Leaders anticipate sufficient learning to publish a data-based peer reviewed journal article in year 9 of the project (personal communication, Samantha Tank, Great Lakes Commission; https://www.greatlakesphragmites.net/pamf/).
Adaptive Co- Management	aspen (*Populus tremuloides*)	grasslands in Canada (Alberta)	Adaptive co-management has been critical for managing aspen incursion into fire-dependent prairie systems because multiple stakeholders are involved, including national park managers and researchers seeking to restore plant communities, as well as indigenous people conducting communal bison hunting. The diverse, long-term perspective resulting from dialogue and engagement among these groups revealed surprising plant community resilience to extreme wildfire. This insight is consistent with indigenous peoples' long-held practice of setting intense late-season fires as an appropriate management strategy, but was unexpected in light of the typical reliance by land managers on low-intensity prescribed burns in springtime (Eisenberg et al., 2019).

viewed as static, particularly when more effective strategies are identified or as new challenges arise (such as herbicide resistance Enloe and Gettys, 2019b).

Trial-And-Error

When data or manager experiences are too scarce to strategically choose among potential management actions, a trial-and-error approach allows managers to use the most promising action(s) while simultaneously evaluating action effectiveness. Managers learn informally from the results of previous management actions, predicting the outcome of future actions based on this knowledge (e.g., should we apply the same treatment again or try something new?), so learning happens after management action is taken. Trial-and-error is perhaps the most commonly applied approach in practice and is sometimes referred to as *passive adaptive management* (Shea et al., 2002; Hasselman, 2017).

The widespread use of trial-and-error likely reflects its perceived low implementation costs, but this approach can result in unreliable information, and strategic planning with efficient use of funds and personnel is constrained by this reactive process (Hilborn, 1992; Wilhere, 2002; Allen et al., 2011). Also, learning about the mechanisms that drive management outcomes is reduced relative to experimental approaches because typically 1) a single treatment is applied (making treatment comparisons impossible), 2) there is no treatment replication over space and time to confirm outcomes, or 3) there is no untreated control or reference to assess gain over "no action" (Wilhere, 2002; Lamers et al., 2015). Thus, the approach has limited generalizability and is confounded with environmental heterogeneity, which can obscure underlying drivers of treatment outcomes (Walters and Green, 1997). Despite these weaknesses, trial-and-error is appropriate when management urgency and public pressure are high (e.g., with conspicuous aquatic plant invaders; Willby, 2007), when immediate reductions at any scale or magnitude are required, and when sustained institutional support is low (Cabin, 2007b; 2007a).

Ecologically-Based Invasive Plant Management (EBIPM)

Ecologically-based invasive plant management (EBIPM) is a management approach that explicitly integrates practitioners' knowledge of and experience with their site(s), along with underlying site-specific drivers of invasion and succession. EBIPM has four main steps: 1) assess the site, 2) determine mechanisms driving invasion, 3) decide which mechanism(s) should guide management, and 4) identify management actions that address underlying cause(s) of invasion (Sheley and Smith, 2012). EBIPM was developed in the context of degraded rangelands, but the principles are relevant to managing invaders broadly, including in wetlands (Krueger-Mangold et al., 2006; Sheley et al., 2006, 2010; James et al., 2010).

Successfully implementing EBIPM (like BMPs) requires a robust knowledge base of the invader, but is distinct from BMPs because of its use of formal site assessments prior to management and its focus on directly addressing the underlying cause of invasion to improve long-term invader reductions (Krueger-Mangold et al., 2006; Sheley et al., 2010). Thus, with EBIPM, action follows learning and reduces uncertainty associated with logistical challenges (*partial controllability*) and ecological drivers of outcomes (*scientific unknowns*) (**Box 1**). These actions also require at least moderate collaborations between scientists and practitioners for EBIPM to be effective. EBIPM can be costly and logistically challenging because of the time investment required to carry out the formal process, therefore, it also requires substantial, sustained institutional support.

Controlled Experiments

In a controlled experiment approach, statistically rigorous experiments are conducted in invaded sites-to-be-restored. Experiment outcomes can help determine management strategies, the underlying invasion mechanisms, and the relative effectiveness of multiple treatment practices (Wagner et al., 2008). Compared to other approaches, experiments may be relatively costly, time-consuming, and risky for invaded ecosystems in urgent need of management (especially where untreated control areas remain unmanaged; Walters and Green, 1997). Thus, this approach is not recommended when management urgency or public pressure is high. However, treatment replication facilitates statistical analysis, hypothesis testing, and the creation of publishable and impactful use-inspired research. Controlled experiments are thus appropriate when there are large knowledge gaps related to ecological drivers of management outcomes (*scientific unknowns*, **Box 1**), especially when conducted over broad spatial and temporal scales to encompass the variability (*environmental variation*, **Box 1**) that often affects treatment outcomes (Kettenring and Adams, 2011). Controlled experiments ideally utilize existing manager knowledge to inform treatment selection (Moon et al., 2015) and capitalize on practitioner involvement to enable treatment of larger areas than otherwise possible given access to management equipment.

Controlled experiments can be formalized into Knowledge Co-production (described below) if practitioners are equal partners throughout the experimental process (Matzek et al., 2015). An extension of a controlled experiment is Adaptive Restoration (Zedler, 2017), which comprises several experiments at moderate to large spatial scales phased sequentially, such that early tests inform later ones (Healy et al., 2015). Similarly, Staged-Scale Restoration includes a sequence of experiments over time, but where early tests are conducted at small spatial scales to identify treatments that are applied to larger areas in later stages (Bakker et al., 2018).

Knowledge Co-production

Knowledge co-production is an intentional, iterative approach to *conducting research* where scientists and practitioners actively collaborate over the entire process of conceptualization (defining problem scope and research questions), implementation (including methods selection), data collection and analysis, and knowledge synthesis and dissemination (Armitage et al., 2011; Moon et al., 2015; Nel et al., 2016; Dubois et al., 2020). Norström et al. (2020) clearly detail the principles for effective knowledge co-production, distinguishing it from controlled experiments. Given the enormity of the challenge invasive species pose for wetlands, invader management success requires the diverse skills sets, knowledge bases, and perspectives that are only possible when practitioners and scientists work together using such an approach.

In knowledge co-production, researchers seek to understand managers' current knowledge, their management goals and objectives, and the constraints that limit management action when developing research programs (Wagner et al., 2008; Ntshotsho et al., 2015). Although discovery of novel actions may result, incorporating manager experience and knowledge is critical for identifying common practices in need of improvement or evaluation (Palmer, 2009; Drescher et al., 2013; Sutherland et al., 2013). From this shared research process, learning yields "usable knowledge" for guiding invasive plant management that is "credible, salient, and legitimate" (Lemos and Morehouse, 2005; Armitage et al., 2011; Moon et al., 2015; Nel et al., 2016). Furthermore, because collaborating with managers facilitates large-scale experimentation due to their access to equipment and land, knowledge co-production is more likely to yield highly generalizable findings compared to other approaches (Kettenring and Adams, 2011). Knowledge co-production is appropriate when neither management urgency nor public pressure are exceedingly high because the process can be lengthy. It requires strong scientist-practitioner collaborations and sustained institutional support for these potentially more time-intensive and costly processes (Bertuol-Garcia et al., 2018b; Dubois et al., 2020); however, such manager involvement very efficiently reduces uncertainty associated with the logistical challenges of management implementation (*partial controllability*, **Box 1**).

Adaptive Management

One approach to developing effective natural resource management strategies is adaptive management (AM) (Holling, 1978; Walters, 1986). AM is often colloquially used to describe a generally flexible approach of sequentially applying different treatments to whole systems (Hasselman, 2017). Often, AM is incorrectly equated with casual "learning by doing" or "learning from mistakes" (Kimball and Lulow, 2019). AM is actually a distinct and formal iterative process used to compare effectiveness of several alternative management actions to achieve a management goal with the help of simple predictive models (Allen et al., 2011). AM is appropriate when the effectiveness of management actions are uncertain (*scientific unknowns*, **Box 1**) and when managers have the ability to test different management actions (Allen et al., 2011). A defining feature of AM is that practitioner and management institutions -- rather than researchers -- define goals, options, and models

(Fischman and Ruhl, 2016), firmly grounding solutions in a real-world management context (reducing uncertainty due to *partial controllability*, **Box 1**). The AM process is a cycle in which 1) outcomes of multiple alternative actions are predicted based on current knowledge, 2) actions are implemented by managers on their lands, and 3) post-implementation monitoring data are used to update model-predicted management outcomes (Moore et al., 2011). Learning begins after the first year actions are implemented and monitored and proceeds via continually updated competing models that adjust to more accurately reflect actual responses observed in the field (Williams et al., 2009).

Its formalized and experimental process distinguishes AM from trial-and-error (Allen et al., 2011), and its iterative nature separates it from other decision-making approaches. AM has in common with EBIPM a specific, formal structure, although AM can proceed without any knowledge about the underlying ecological processes driving invasion. Because answers are not rapidly available using AM, it may not be appropriate when public pressure to actively manage an invasion is high. AM has important, rarely acknowledged limitations (see Shea et al., 2002), such as requiring substantial institutional support and funding to sustain it. Efficient application of AM requires considerable investment to develop and maintain a centralized database and decision support tool (Moore et al., 2011). Despite the global importance of wetland conservation and restoration, as little as 30% of AM literature focuses on aquatic systems (Westgate et al., 2013).

Adaptive Co-management

Adaptive co-management blends the "learning" aspect of AM with the "linking" function of collaboration (Armitage et al., 2009; Nourani et al., 2018) by involving stakeholders with diverse interests for power sharing and negotiation. Collaboration reduces uncertainty by eliminating potential management actions from consideration that might be logistically limited by stakeholder related constraints (reducing *partial controllability*, **Box 1**). Adaptive co-management's defining feature is its incorporation of multiple levels of governance. Adaptive co-management systems may or may not apply the explicit AM framework described by Williams (2011). Adaptive co-management goes beyond natural resource management goals, encompassing more society-focused goals such as improved human well-being and policy innovation (Armitage et al., 2011). AM is usually supported by national governmental management agencies (e.g., US Department of the Interior, Australia's CSIRO), reflecting *federal responsibility*. In contrast, adaptive co-management's institutional context is *local responsibility,* based within and supported by local governmental agencies or organizations (Hasselman, 2017). Since wetlands are often protected on a national level but impacted by local government decisions, the linkages that adaptive co-management facilitates should be particularly advantageous in this context (e.g. Olsson et al., 2004).

Sustained institutional support and management urgency must be high for adaptive co-management to be effective. Unique to this approach, key individuals have long-term connections to the land being managed and, therefore, have added incentive to mediate conflicts to facilitate policy development (Armitage et al., 2009, 2011). Interestingly, many recent natural resource management governance initiatives adhere to the basic principles of adaptive co-management without aiming to do so by design, evoking a justification for this approach as an inherently good fit for such challenges (Plummer et al., 2017).

Specific Actions to Overcome Obstacles to Effective Invasive Species Management

The structured approaches described above can enhance and integrate wetland invader science and management, but the full framework of any structured approach may be beyond the scope of many organizations. Thus, we also highlight smaller concrete steps ("specific actions") that can lead to invader management improvements. Often, scientists are portrayed as having the primary responsibility for initiating one of these actions (Matzek et al., 2015; Funk et al., 2020), but practitioners are equally well positioned to do so (Bertuol-Garcia et al., 2018a). In either case, the most impactful actions will often engage community stakeholders as well (Lubchenco and Rapley, 2020; Carter et al., 2021). In the following sections we discuss specific actions that can be initiated by different actors—scientists, practitioners, or community stakeholders—to reduce wetland invader management constraints via advances in six key domains (**Figure 3**) that can be used across a range of project stages, funding levels, invasion contexts, and institutional settings.

Improve the Exchange of Knowledge and Ideas Between Scientists and Practitioners

When managers and scientists co-design and co-implement invasive species management experiments, the exchange of ideas, knowledge, and experience is central to the process, whether implemented as one of the specific structured approaches described above (see *Structured Approaches to Improve Management of Wetland Plant Invaders*) or more general approaches (e.g. "translational ecology", Hallett et al., 2017; "bi-directional information exchange", Bertuol-Garcia et al., 2018b). These strategies recognize the substantial value that can be gained by leveraging expert knowledge from practitioners (Sher et al., 2020), which is often overlooked and undervalued (Drescher et al., 2013).

Use Cooperative Extension to Unite Scientists and Practitioners

Cooperative Extension programs at public land grant universities in the U.S. are a formal, funded mechanism to bridge the gap between researchers and practitioners (Gornish and Roche, 2017, 2018). Extension was created to address agricultural topics (Osmond et al., 2010), but it has since expanded to address many non-agricultural topics, including natural resources. Extension employees focus their use-inspired research and outreach on locally-relevant issues such as managing invasive species of interest to wetland managers and other stakeholders

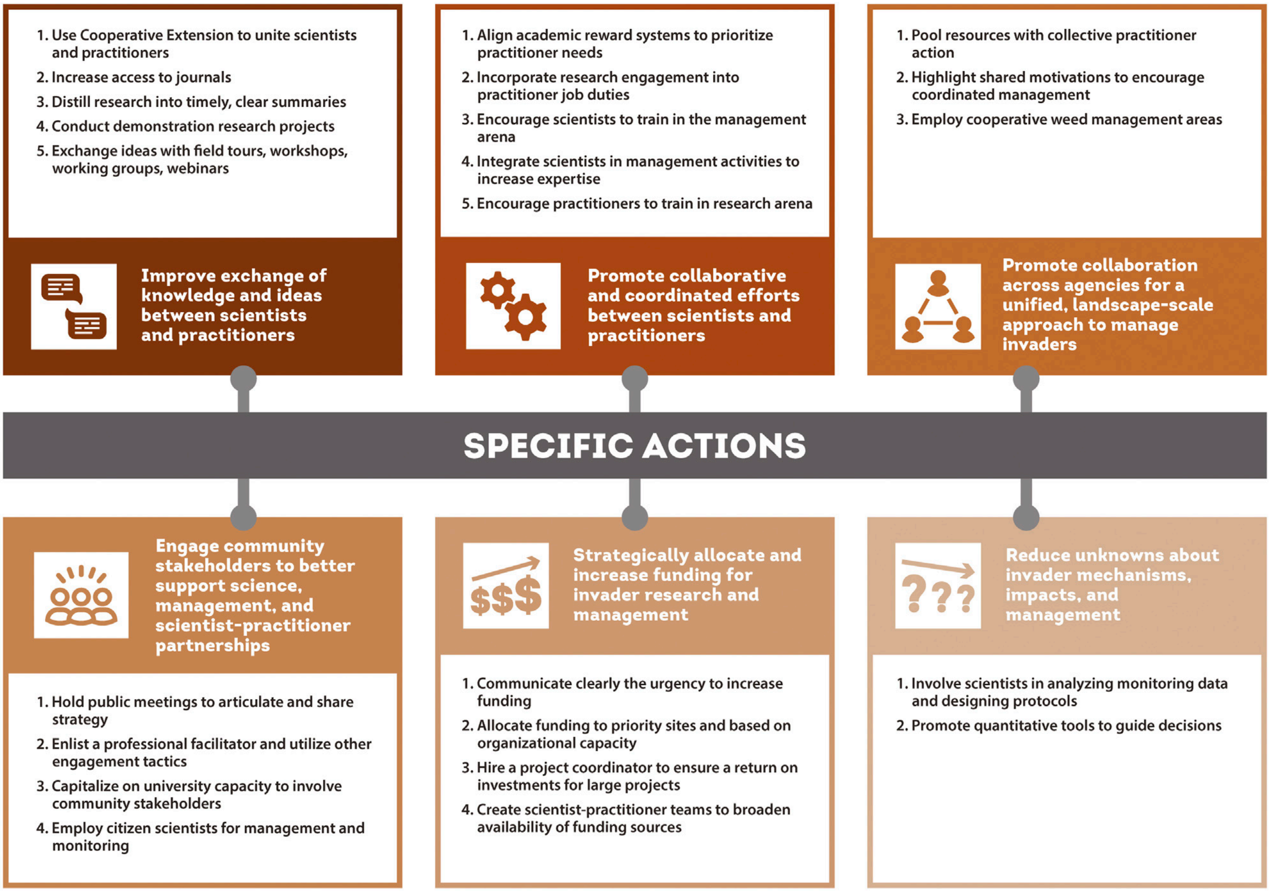

FIGURE 3 | Many concrete steps can be taken by scientists and managers to improve science-based management of wetland invaders. These specific actions tend to be collaborative, rather than the action of people in just one role (practitioner or scientist), and in many cases they represent intentional actions needed to bridge the implementation gap. Some of these specific actions are already frequently in use whereas others will require additional consideration or renewed attention. Regardless, on the whole these specific actions should be feasible for many organizations and contexts when adopting an overarching structured approach might be unworkable.

(Osmond et al., 2010; Gornish and Roche, 2017, 2018). They also facilitate the exchange of knowledge and experience between scientists and managers (Osmond et al., 2010; Hoffman et al., 2015; Gornish and Roche, 2018). Furthermore, the metrics of "success" that affect career advancement within Extension include behavioral changes in response to knowledge sharing (e.g., changes in practitioner management strategies), thus overcoming some of the "academic culture and job duty" constraints previously described.

Increase Access to Journals

Much of the scientific literature is unavailable to practitioners whose organizations, firms, and agencies do not subscribe to expensive academic journals (Prendergast et al., 1999; Hulme, 2014). Many researchers are moving towards open access publication, in part to ensure broader access to their research by practitioners (Hulme, 2014; Funk et al., 2020); however, open access still only represents about 15% of peer-reviewed journal articles about invasive species (Matzek et al., 2015). Open access publication is expensive, for the researcher or their institution. Nonetheless, the payoffs are substantial regarding increased research access by practitioners. For example, increasing journal access can inform managers about the most effective treatments while also preventing ineffective invasion management (e.g., Dettman and Mabry, 2008).

Distill Research Into Timely, Clear Summaries

Brief research summaries are more likely to promote incorporation of research findings into wetland invasive species management than papers written primarily for a scientific audience (Dettman and Mabry, 2008). Such summaries were primary information sources to support management decision-making in a survey of invasive species managers (Beaury et al., 2019) and significantly increased consideration of recent research in management decisions by surveyed conservation biologists (Walsh et al., 2015). Since research summaries can be prepared even as work is ongoing, they can enable practitioners to adjust management strategies in response to the latest scientific insights (Hallett et al., 2017). To nudge scientists to produce such "one-pagers," rewards such as those presented by the Conservation Ambassador Program (e.g. financial honoraria, letters of acknowledgement) should be considered as potentially effective incentives (Nadkarni, 2004). Such research summaries can be curated into databases to facilitate broad access (e.g. Element Stewardship Abstracts, https://www.invasive.org/gist/esadocs.html; or France's Invasive Species Resource Center, http://www.gt-ibma.eu, Sarat et al., 2017).

Conduct Demonstration Research Projects

Demonstration projects are an effective way to evaluate invasive species management approaches and feature successful outcomes (Renz et al., 2009) that have recently been prioritized by the US Environmental Protection Agency's Wetland Program Development Grants. Demonstration projects provide visual records of management activities and public site access (often with infrastructure like boardwalks and educational signage) to maximize learning (Bohnen and Galatowitsch, 2005; Renz et al., 2009). When scientists and managers partner to conduct demonstration projects, scientists gain experience working with practitioners and understanding the constraints practitioners face, and practitioners and scientists can address scientific unknowns and management uncertainties. For example, the Spring Peeper Meadow restoration in Chanhassen, MN, United States, demonstrated the investment required to restore a high quality prairie wetland in an area heavily impacted by invasive reed canarygrass, *Phalaris arundinacea* (Bohnen and Galatowitsch, 2005), providing guidance for recovery following invasive species removal (Galatowitsch, 2006).

Exchange Ideas With Field Tours, Workshops, Working Groups, and Webinars

In addition to demonstration projects, other approaches for sharing science-based invasive plant information include working groups, symposia, workshops, short courses, trainings, webinars, and field tours (Matzek et al., 2014; Sarat et al., 2017; Gornish and Roche, 2018; Beaury et al., 2019). Success in implementing any of these approaches requires mutual respect among participants and exchanges centered on their differing experiences and sources of knowledge (i.e., tacit vs. explicit knowledge). Thoughtful content curation, combined with informal conversations, is also critical. Such events catalyze learning and new collaborations and coordinating management (Gibbons et al., 2008; Sarat et al., 2017). One notable example is the Ohio Invasive Plants Council conference, United States, which brings together managers and scientists for presentations, posters, and informal discussions regarding invasive plant ecology and management (www.oipc.info/). In addition, Lavoie and Brisson (2015) detail a manager training program to integrate relevant ecological information on key invasive species in Quebec, Canada, drawing on scientific insights from their research programs and management insights from practitioners.

Promote Collaborative and Coordinated Efforts Between Scientists and Practitioners

Specific steps can be taken to promote not just idea sharing but collaboration between scientists and managers. Part of the solution involves shifts in job descriptions and career reward systems. Beyond that, reciprocal training experiences between scientists and managers can enhance understanding of job obligations and how best to overcome constraints to collaboration.

Align Academic Reward Systems to Prioritize Practitioner Needs

Use-inspired research and manager engagement is unrewarded by many scientists' career advancement systems (Whitmer et al., 2010). Instead, career reward systems should be based on metrics that better serve invasive species management such as the USDA NIFA logic model that emphasizes impact. This approach prioritizes "outcomes" beyond knowledge development, assessing how that knowledge yields changes in actions (e.g., the adoption of new, improved invader management techniques) and in conditions (e.g., wetland invader reductions). But how could that be incorporated into career advancement metrics?

We emphasize four modifications for incentivizing scientists to engage more effectively with managers and to conduct use-inspired research. First, alternative methods of science delivery that focus on accessibility to managers (such as research summaries, Cooperative Extension documents, webinars; Dettman and Mabry, 2008; Whitmer et al., 2010; Caudron et al., 2012) can broaden the definition of what is considered acceptable academic scholarship (Hoffman, 2016). Second, reward structures can recognize that although research published in more applied and use-inspired research journals may not be as highly cited, and the journal impact factors may be lower compared with those centered on basic or fundamental research (Dettman and Mabry, 2008; Hulme, 2014), that does not necessarily diminish utility and importance of the research. Third, reward structures can account for meaningful engagement with managers, encouraging scientists to prioritize "service" beyond their academic bubbles (Dettman and Mabry, 2008; Whitmer et al., 2010; Caudron et al., 2012). This change would acknowledge the enormous time commitment that developing and maintaining such relationships requires (Whitmer et al., 2010; Enquist et al., 2017; Hallett et al., 2017). Finally, similar to logic models for USDA NIFA, reward structures must document changes in manager actions and wetland conditions that assess the impact of scientists and their research on society (Chapron and Arlettaz, 2008; Arlettaz et al., 2010; Whitmer et al., 2010).

Incorporate Research Engagement Into Practitioner Job Duties

Agency leadership can support practitioner involvement in research (Allen and Gunderson, 2011). For example, agencies can include research involvement in practitioner job descriptions or even create new positions and processes to support management-research partnerships (Carter et al., 2020). Agencies can also establish reward systems for managers to sustain these long-term commitments, as temporal consistency is critical for addressing long-term resource management issues (Gibbons et al., 2008) including those related to invasion (Prager, 2010).

Encourage Scientists to Train in the Management Arena

For scientists to more deeply understand the management arena, they need meaningful ways to experience the culture, constraints, and concerns of managers (Renz et al., 2009). Such experiences also facilitate future scientist-manager collaborations and potential funding opportunities for scientists seeking to do research relevant to managers. Internships, sabbaticals, "professional cross-placements", and other training programs serve this purpose at any career stage (Gibbons et al., 2008). A notable example (not specific to invasive plant management) is the Smith Fellows Program for postdoctoral scientists in conservation biology, which emphasizes collaboration and mentoring partnerships with scientists *and* practitioners. Scientists can also take sabbaticals within "interface organizations" that specialize in integrating science and management (Osmond et al., 2010) or within land management organizations. For mid-career scientists, the Earth Leadership Program provides training in science-management integration skills and how to pass them on to students. Junior scientists can apply for internships and fellowships to support the creation of science-based policy (e.g., through the American Association for the Advancement of Science; Jenkins et al., 2012). And for scientists at any stage, valuable perspectives on management duties and constraints can be gained, and long-term partnerships initiated, by volunteering on management projects such as invasive species removal or native planting workdays.

Integrate Scientists Into Management Activities to Increase Expertise

Beyond encouraging scientists and managers to receive training in each others' primary domains, we argue that integrating researchers into management activities would increase management capacity for invader-dominated wetlands in several key ways. First, and perhaps most obviously, when data are routinely collected to measure management outcomes, adding academic personnel to the project allows academic and management institutions to pool their human, technical, and financial means and leverage those resources to meet management goals (D'Antonio et al., 2004; Caudron et al., 2012). Such scientist involvement can increase capacity to implement treatments and monitor outcomes even without additional internal management institution funds. When this involvement occurs as undergraduate or masters thesis research, invader management as well as academic research programs may benefit (Matzek et al., 2015), enabling research funding for current or future projects. Going a step further, Caudron et al. (2012) recommend positioning researchers outside purely academic settings, establishing "joint scientist positions" that are shared among institutions to ensure collaborative work and the incorporation of research findings into decision-making procedures.

Encourage Practitioners to Train in the Research Arena

Although organized course work for practitioners is often dismissed as a low priority for agencies, managers who train in the academic arena may experience fewer scientific literacy barriers when translating research to management practice (Sunderland et al., 2009). This training can take different forms. For instance, agency-supported coursework programs have been developed, including the US Fish and Wildlife's National Conservation Training Center, whose mission is "enhancing the competencies of dedicated conservation professionals...and serving as a think tank where conservation professionals can jointly solve the conservation issues of our day" (Moore et al., 2011; US Fish and Wildlife Service, 2015). So-called "boundary organizations" can also provide training and tools that connect relevant science with practitioners. For instance, NatureServe supports the Ecosystem-Based Management Tools Network, which organizes webinar case studies that allow practitioners to rapidly evaluate whether newly-developed tools (e.g. sea level rise impact prediction models) could improve their outcomes (Cook et al., 2013).

Lastly, courses and certifications that provide more specific practitioner training can also be quite effective. Lavoie and Brisson (2015) describe a course delivered by researchers to detail the science behind effective invasion treatments, as well as methods and costs, that was shown effective in transferring information. Continuing education credits were available, giving the training university backing and enhanced credibility. Practitioner efforts to seek training for effective wetland and invasive plant management can be rewarded with credentials from programs such as the Society of Wetland Scientists' Professional Wetland Scientist certification and the Society for Ecological Restoration's Certified Ecological Restoration Practitioner program (Nelson et al., 2017).

Promote Collaboration Across Agencies for a Unified, Landscape-Scale Approach to Manage Wetland Invaders

Invasive species do not recognize land ownership boundaries, and the scale of wetland invasion drivers is distinct from social organization scales (Cumming et al., 2006; Epanchin-Niell et al., 2010; Lubell et al., 2017; Graham et al., 2019). Efforts should be prioritized at broad scales and implemented at local scales where the most suitable sites can be selected (Gilby et al., 2021). But this requires coordination and collaboration across public/private organizations and management jurisdictions (Lubell et al., 2017). Coordination and collective action are important so that managers' efforts in one parcel are not ruined by neighbors who fail to control their wetland invaders (the challenge of "management mosaics"; Epanchin-Niell et al., 2010; Aslan et al., 2021).

Pool Resources With Collective Practitioner Action

Management advances are more likely when managers pool resources to meet shared invader management goals. Such collective action by land managers includes potential sharing of financial, human, and equipment resources to overcome mismatches between the scales at which invasions and management actions occur. Such informal partnerships may also be a first step towards overcoming constraints related to differing agency jurisdictions and institutional silos (Epanchin-Niell et al., 2010; Graham et al., 2019; Carter et al., 2020).

Highlight Shared Motivations to Encourage Coordinated Management

Collaborations can be mandated and joint efforts facilitated with funding initiatives, but successful coordination and information sharing is more likely when the parties involved are motivated by shared interests (Sayles and Baggio, 2017). To counter the tendency of individuals and agencies to work mostly within their own governance silos, landscape-scale collaborative relationships should be mobilized around shared goals and motivations (Sayles and Baggio, 2017; Graham et al., 2019). Such an approach occurred across diverse agencies and organizations with *Phragmites* management in Great Salt Lake wetlands (Rohal et al., 2018). Initially, scientists surveyed wetland managers to determine their shared goals and motivations. Meetings organized to discuss these survey results served as the foundation for long-term inter-organization manager collaborations and productive scientist-manager partnerships. In another example, the inter-agency Great Lakes *Phragmites* Collaborative engaged stakeholders by centering on a "common agenda" to align resources with priorities, making substantive progress towards identifying shared *Phragmites* management goals (Braun et al., 2016). Coordinated management can also result from more centralized efforts, as with the California State Coastal Conservancy overseeing the invasive *Spartina* project to catalyze management of that species across California (Kerr et al., 2016).

Employ Cooperative Weed Management Areas

Developing and sustaining landscape-scale management requires resilience to budget cuts and grant timelines, personnel changes, land ownership changes, and evolving management goals (Adams et al., 2016). One approach that can facilitate such changes is Cooperative Invasive Species (or Weed) Management Areas (CISMA or CWMA, www.invasive.org/cismas; Epanchin-Niell et al., 2010). These organizations are regionalized partnerships in the US of federal, state, and local representatives that manage invasive plants in a specific area. They allow for enhanced resource pooling and management coordination across the focal area, and they facilitate knowledge sharing about the biology and control of invaders.

Engage Community Stakeholders to Better Support Science, Management, and Scientist-Practitioner Partnerships

Engaging a diversity of community stakeholders can overcome many challenges faced by invasive species researchers and managers by building interest, enthusiasm, accountability, volunteer labor, political support, and increased funding for projects (Howell et al., 2012; Davis, 2018). Engaging community stakeholders may require a more strategic approach than engaging those already involved in the project and should center on the principles of collaboration, cooperation, and communication (Howell et al., 2012; Davis, 2018).

The effort required to *sustain* meaningful and lasting engagement is not business-as-usual for either researchers or managers; recognizing the profound differences in investment and responsibility for all partners (Gonzalo-Turpin et al., 2008) will make expectations more realistic. However, devoting resources to building trust among constituencies can result in substantial support for producing science relevant to management (Davis, 2018; Shackleton et al., 2019a). Below we provide example strategies. We also suggest following Novoa et al. (2018)'s 12 steps to ensure stakeholders are appropriately considered in decision-making for invasive species management, including the particularly helpful tip to intentionally select specific individuals to engage for maximum influence ("context setters") and impact ("key players").

Hold Public Meetings to Help Articulate and Share Strategy

To effectively solicit information and participation from stakeholders, multiple forms of communication should be instituted early and sustained as the community changes over time (Howell et al., 2012). Such approaches include holding public meetings for involved parties, using formal participatory planning techniques, and forming an advisory board (Howell et al., 2012). Throughout, project leads must be explicit about project goals and both management and monitoring actions (Bernhardt et al., 2007; Howell et al., 2012). Meetings should be preceded and followed by frequent and clear communication that leads to familiarity with different workplace cultures, thereby facilitating the deep stakeholder dialogue that is often critical for problem solving (Howell et al., 2012; Enquist et al., 2017). Gornish et al. (2021) demonstrate that a basic guideline is to incorporate meetings into stakeholder events (rather than inviting stakeholders to your own event).

Enlist a Professional Facilitator and Utilize Other Engagement Tactics

Engagement can be optimized if the local context is used to drive the most appropriate choice of engagement approach (e.g. top-down vs bottom-up communication), as many affected parties as possible are represented, and a professional facilitator is enlisted to aggregate information and help overcome bias related to power dynamics (Shackleton et al., 2019a). Further, engagement is given the best chance for success if leaders adhere to a set of core principles underlying discourse-based approaches: discussion involvement is fair and impartial; responsible parties are demonstrably accountable and trustworthy; the process is accessible, participatory, and inclusive for all parties; and the decision making process is transparent and honest (Emborg et al., 2012).

Capitalize on University Capacity to Involve Community Stakeholders

To address the unassigned nature of much of the work needed to bridge the science-implementation gap, scientists can leverage established stakeholder engagement programs. Gornish and Roche (2017) point out that the Cooperative Extension (CE) system, which already exists in US land-grant universities, has been engaging community stakeholders in projects for over 100 years (surveying stakeholders for programmatic priorities, hosting listening sessions, and delivering recommendations with field days and workshops). CE is rarely referenced in this context, but, by working with CE personnel, academics may be able to overcome the lack of training that often limits their own ability to engage stakeholders and do solutions-oriented work, while managers may be able to use their state and county level CE networks to engage relevant stakeholders (Gornish and Roche, 2018).

Universities (land-grant and otherwise) could also promote community stakeholder engagement by 1) incentivizing partnerships with the community, 2) rewarding academics whose work produces solutions relevant to the general public, 3) facilitating more rapid solution production with prototypes and iterative product development *sensu* the tech industry, and 4) promoting "outward-facing" units that unite use-inspired and basic science departments to steer resources like university infrastructure and new positions to focus on societal needs (Keeler et al., 2017).

Employ Citizen Scientists for Management and Monitoring

Volunteers can be a critical part of invasive species research and management project success (Howell et al., 2012). Networks of citizen scientists have proven to be essential in the early detection of invasive species and can also help stretch limited funds for invasive species science and management (Crall et al., 2010; Gallo and Waitt, 2011; Larson et al., 2020). Community members may be motivated to participate in other aspects of invasive species work such as research or management project implementation (e.g., invader treatments or post-treatment plantings) or longer-term post-treatment monitoring. In turn, citizen scientists and other volunteers can serve as ambassadors to "spread the word" about invasive species' impacts and on-going management projects, thereby enhancing the degree of community engagement around invasive species management issues generally.

Strategically Allocate and Increase Funding for Invader Research and Management

Increasing available funds to manage wetland plant invaders will lead to more effective programs if applied strategically. In addition to sweeping systematic change, there are several approaches to improve management funding that fit within current institutional scenarios. Inevitable financial shortfalls mean it is critical to optimize existing resources by ensuring judicious use of funds.

Communicate Clearly the Urgency to Increase Funding

Managers often cite an urgent need to act (Dettman and Mabry, 2008) that, if it were more clearly represented and communicated, could support lobbying efforts. To better match the level of funding to the urgency and scale of the need, cost-benefit analyses of invader management should be more widely used (Courtois et al., 2018) and expanded to consider both estimates of the value of ecological losses due to wetland invaders, as well as impacts on ecosystem function (Martin and Blossey, 2013). Ideally, cost-benefit analyses should also compare various management options including "no action" (rather than just those of a single treatment; Radomski and Perleberg, 2019) and consider the implications of underfunded and therefore incomplete removal, such as increased ecological or retreatment costs following reinvasion due to suboptimal control measures (Jardine and Sanchirico, 2018). These estimates are difficult to quantify but are key to presenting realistic return-on-investment expectations from successful management (Epanchin-Niell, 2017). Such assessments can also be leveraged to shape policy. For instance, linkages among scientists, practitioners, and legislators can help generate government funding for the long term efforts needed to control the most problematic wetland invader species (e.g. *Phragmites* austrails; Young and Kettenring, 2020).

Allocate Funding to Priority Sites and Based on Organizational Capacity

Invasive species management will always be under-funded, so making the most of existing funds by optimizing decision-making strategies is key for maximizing gains (Courtois et al., 2018). Systematic regional or conservation planning, which provides methods for prioritizing conservation efforts across multiple sites based on benefit maximization and cost minimization, can be extended to invasive wetland plant management (Long et al., 2017; Strassburg et al., 2019). For example, by monitoring the outcome of eradication efforts across 346 *Phragmites* populations of varying size for 7 years, researchers were able to prioritize sites for management, based in part on how patch size influenced the probability of reaching management goals (Quirion et al., 2018).

The efficient use of management funds for invasive species control also requires allocating resources based on the abilities of those responsible for carrying out management. The institutional capacity of an organization tasked with restoration must coincide with the degree of ecological degradation encountered (Galatowitsch and Bohnen, 2020) to ensure that the group responsible for a project has demonstrated sufficient restoration proficiency (e.g., by showing a history of grants management, adequate planning and goal setting, and sufficient recordkeeping). Unfortunately, many agencies are required to select contractors based only on the lowest bid. While keeping costs low is an important consideration, this should never come at the expense of meeting project goals.

Hire a Project Coordinator to Ensure a Return on Investments for Large Projects

The efficient use of funds is particularly important in large and expensive wetland restoration projects, where stakes are especially high for achieving project goals. In such projects, cooperation and follow-through are essential because budgets tend to be complex and management actions often span many sites over large areas. A designated coordinator who is invested in, and therefore takes responsibility for, project outcomes can provide the level of communication, problem solving, and support for manager participation that is necessary to sustain such large projects (Moore et al., 2011). Despite substantial costs to support such a position, ensuring the success of highly complex restoration projects may often hinge on this critical person (Moore et al., 2011).

Create Scientist-Practitioner Teams to Broaden Availability of Funding Sources

To broaden avenues for funding use-inspired research, researchers and managers can jointly apply for funding, using manager insights to strengthen proposal relevance for management, and qualifying for funding sources that would otherwise be unavailable to researchers alone (Caudron et al., 2012). For instance, grants funding "field trials" and "demonstration projects" can support researcher and manager needs by integrating experiments with the development of practical tools (Renz et al., 2009). Although

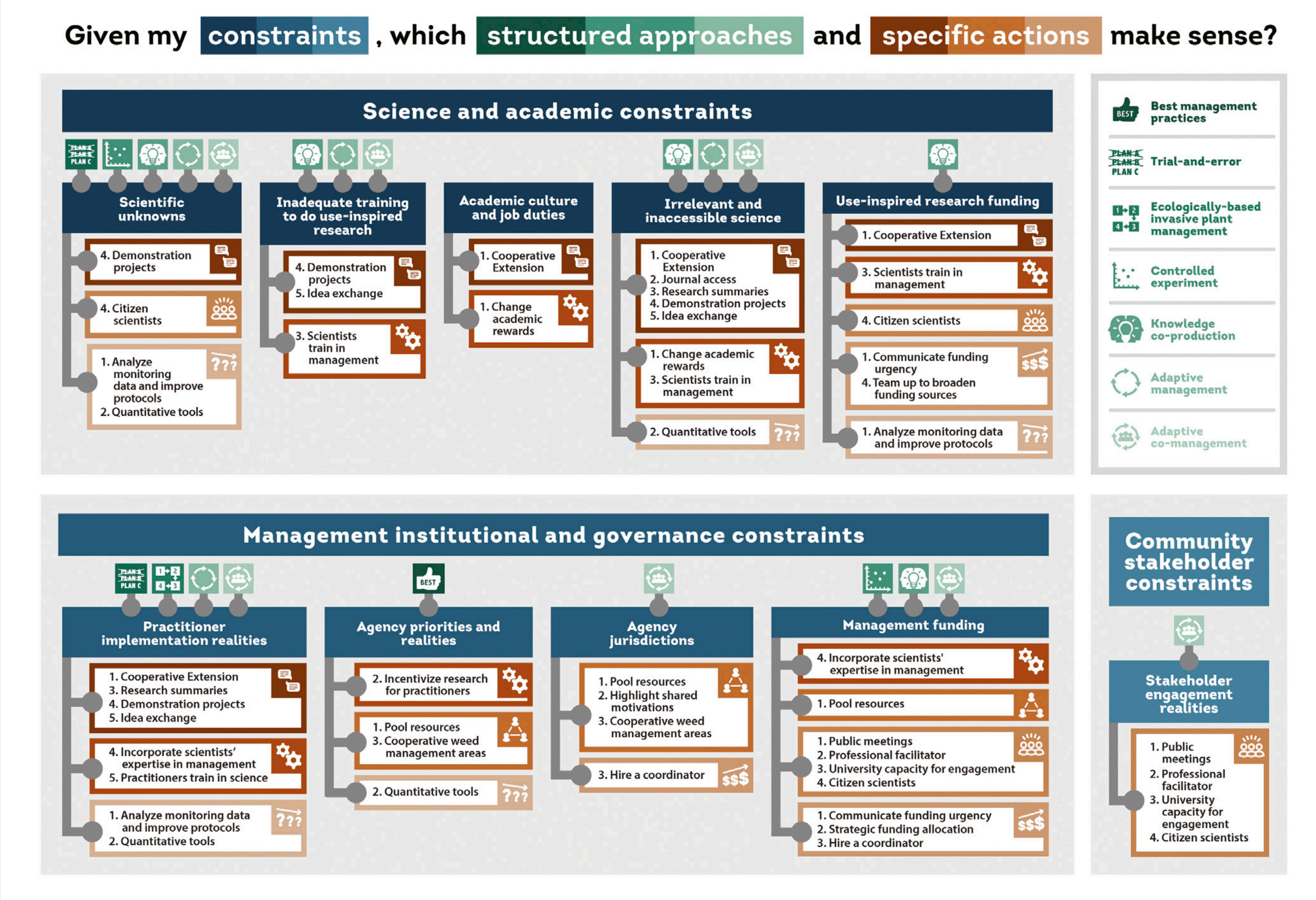

FIGURE 4 | Addressing constraints: Despite the numerous and diverse constraints to wetland invader management, a portfolio of structured approaches and specific actions can be employed to overcome them. However, some constraints (e.g., "Academic culture and job duties") are not addressed by any or most of the structured approaches we describe. Other constraints can be accomplished by many different structured approaches (e.g., "Practitioner implementation realities") and specific actions (e.g., "Funding for management"). How each structured approach or specific action is carried out in practice is poorly documented. Furthermore, the extent to which constraints are addressed will vary by the degree to which a structured approach or specific action is implemented.

funding amounts can be substantially smaller and shorter term (e.g., on annual grant cycles tied to a state's fiscal year; Hallett et al., 2017; Funk et al., 2020), the success rate of such grants can be substantially higher than those for many federal funding agencies, and early demonstrations of success can even further enhance the likelihood of additional funding. In one example involving invasive *Phragmites* management, researchers teamed up with managers to implement large-scale management experiments, securing external funding from 13 state and federal agencies, non-profits, and foundations to fund a 5 year project with one M.S. student and one Ph.D. student (Rohal et al., 2018; 2019a; 2019b). Such an approach requires one or more invasive species or high priority wetland complexes around which to motivate diverse organizations to pool resources.

Reduce Unknowns About Invader Mechanisms, Impacts, and Management

Improving wetland invader management outcomes in many cases depends on reducing unknowns regarding why certain invasive species are successful, exactly what impacts they have, and how best to manage them. Here, we recommend specific actions that leverage relationships between scientists and managers to reduce these scientific unknowns.

Involve Scientists in Analyzing Monitoring Data and Designing Protocols

Many natural resource agencies recognize the importance of—and commit resources to—long term monitoring that can yield valuable management insights (Lindenmayer et al., 2012). Yet, much of these data remain untapped for management decision-making (Kneisel et al., 2020). Researchers and managers alike would benefit from researchers using existing data sets to evaluate invader control outcomes, rather than only collecting data from their own experiments. Such partnerships are rare but effective. For example, Copeland et al. (2019) analyzed an existing database with 25 years of rangeland vegetation data from 491 sites to evaluate approaches for controlling invasive woody species and promoting native species. At even broader scales, Ladouceur and Shackelford (2021) highlight the value of aggregating such datasets via efforts like the Global Restore Project (www.globalrestoreproject.com), which aims to inform decision-making by creating a data clearinghouse for restoration projects globally. Many of these datasets will likely include data relevant for invasive plant management, given that controlling invasives is often central to restoration. We speculate that such datasets may be particularly common for wetlands, because of strict post-restoration monitoring requirements (e.g., Matthews et al., 2009b, 2009c; Matthews and Spyreas, 2010). We underscore the importance of establishing and analyzing large-scale, long-term datasets from wetland restorations initially dominated by invasive plants.

Beyond the *post hoc* use of existing datasets, advances in invader management would also benefit from decision-making agencies creating permanent scientist positions to maximize the utility of monitoring data. Such personnel could help outside researchers customize their research programs and encourage data sharing to evaluate potential management interventions (Jenkins et al., 2012). Caudron et al. (2012) contrast learning from data in a case study of watershed-wide fisheries management, where data collected in the 20 years prior to scientist involvement was underutilized, but after scientists became involved, data-driven management plans were used to maintain fish populations.

Promote Quantitative Tools to Guide Decisions

Quantitative modeling is central for prediction in invasive plant management. For example, insights can come from using demographic models to identify key life stage(s) that influence an invader's population growth or spread and make predictions about population growth under various management strategies (Brown et al., 2008; Brudvig, 2017). Pardini et al. (2009) used this approach to inform management of the biennial woodland invader garlic mustard (*Alliaria petiolata*), suggesting that their management recommendations may also be relevant for other stage-structured invasive species with similar life histories. Because many wetland invaders share commonalities with respect to their life histories (e.g., highly clonal, perennial species with wind- and gravity-dispersed seeds), an analogous approach could yield useful insights in these systems. Tools to model spatial spread dynamics are also common and can be used to predict the outcomes of various management strategies (e.g., Eppinga et al., 2021). Quantitative modeling also underpins decision support tools (DSTs), which offer powerful means to select the optimal management approach when there is uncertainty about how best to manage (as in adaptive management). DSTs require high computational complexity, which can be a barrier to implementation (Williams and Brown, 2016; Memarzadeh and Boettiger, 2018), but their utility may justify overcoming this constraint, especially when use is maximized with a clear user interface and output graphics (Rose et al., 2016) and explicit plans for distribution and user support (Moore et al., 2011).

CONCLUSION

The "holy grail" of invasion ecology is to develop management strategies with predictable outcomes. The premise is that by understanding the unifying mechanisms underlying invasion and successional dynamics of wetland plant communities across sites and landscapes, management outcomes can be better predicted. But such thinking ignores the fact that invader management is also driven by social, institutional, and governance constraints. Here we reorient the conversation to highlight how all actors—managers, researchers, and community stakeholders—have a role to play.

The need to overcome these constraints and improve management is clear. It can be daunting for practitioners and scientists to generate the inertia to adopt novel solutions or to pivot from structured approaches or specific actions that are familiar, even if a "go-to solution" has not been overwhelmingly effective in the past. We have provided a portfolio of potential solutions, highlighting when these solutions might be particularly effective (**Figure 4**). In collaborative environments, where a path forward must be determined with input from multiple parties, this document can be used to provide a shared vocabulary for selecting the most appropriate solution. We advocate consideration of all potential solutions, rather than prescribing one. The most appropriate solutions will emerge with an honest assessment of the most relevant constraints for a particular scenario.

Wetland conservation lags behind efforts in other ecosystems, resulting in a great emphasis on restoration to recover lost ecosystem function (Moreno-Mateos et al., 2012; Kingsford et al., 2016). Yet, wetland restoration is often limited by invasive plant species, underscoring the importance of improving invasive plant management. Taking the effort to improve restoration of invaded wetlands will be less daunting if we realize that even if we are not 100% successful, progress is still progress, and failing to reach goals does not justify abandoning efforts (Young and Schwartz, 2019). Such continual improvement is crucial for the goal of restoring wetlands.

AUTHOR CONTRIBUTIONS

All authors provided insight from their own experiences in researching invasive plant management (collectively 80 years of experience) and have made a substantial, direct, and intellectual contribution by conceptualizing this work, researching the ideas, and writing and revising the manuscript.

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