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Phosphorus sustainability through coordinated stakeholder engagement: a perspective

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Abstract
In this Perspective we take an in-depth look at what coordinated stakeholder engagement could entail for phosphorus sustainability. The element phosphorus is critical to life on Earth and to the continued functioning of society as we know it. Yet, how society uses phosphorus is currently unsustainable, both as a resource in support of global food production where inequitable distribution creates food security challenges, but also from an environmental aspect, where mismanagement has led to negative impacts on the quality of agricultural soils, human health, and freshwater and marine ecosystems. A number of initiatives and cross-sector consortia have come together to address sustainable phosphorus management at either global or regional scales. However, these efforts could benefit from a more coordinated approach to stakeholder engagement to identify the diversity of needs and perspectives involved in this complex challenge. Herein we examine some examples of different approaches to developing such coordinated stakeholder engagement in other areas of environmental sustainability. We consider how to apply the lessons learned from those efforts toward stakeholder coordination in the realm of phosphorus sustainability. Particularly, we discuss the value of a coordinating body to manage the communications and knowledge sharing necessary to develop trust and cooperation among diverse stakeholder groups and to transition society to more sustainable phosphorus use.

Keywords Stakeholder coordination · Stakeholder engagement · Phosphorus sustainability · Sustainability transitions

1 Introduction

Our society is broadly reliant on phosphorus. Phosphorus is currently used in a range of industrial applications, food and agricultural products, as well as consumer products. Out of all our uses of phosphorus, food production is by far the greatest consumer of global phosphorus, with 80% of mined phosphate applied as agricultural fertilizer, primarily in industrialized nations (Rhodes 2013). Despite our heavy dependence on phosphorus in agricultural production, there are a number of inefficiencies that result in "phosphorus leaks" throughout the value chain. Excessive fertilizer application results in legacy phosphorus buildup in soils affecting soil health, as well as agricultural runoff that adversely impacts freshwater ecosystems and the quality of drinking water sources. Inefficient phosphorus management also results in industrial and biowaste landfilling and wastewater plant discharge containing effluents high in phosphorus (Rhodes 2013; Doydora et al. 2017; Sharpley et al. 2018). At the same time, Earth's phosphorus deposits are a finite resource that are limited in minable quantities to only a few geographic areas. It is becoming increasingly clear that the current indiscriminate use and management of this irreplaceable element will not be economically viable in the long term (Cordell et al. 2011; Rhodes 2013).

The 2022 report by the Our Phosphorus Future project (OPF report) details the challenges of transitioning society from its linear and inequitable use of phosphorus toward more sustainable circular management (Brownlie et al.

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2022). Leveraging research and expertise from more than 100 scientists and industry experts over a 5 year period, the OPF report notes that the planetary boundary, or safe operating space for the biogeochemical flow of phosphorus where both humanity and nature thrive, has been exceeded at both regional and global scales for over a decade. This can impact other planetary boundaries and have disruptive human and environmental consequences (Rockström et al. 2009; Brownlie et al. 2022). The uneven distribution of phosphorus globally as both a resource and in use, coupled with the cumulative effect of phosphorus pollution across urban and rural regions precludes simple policy solutions for managing this important yet finite resource. The OPF report does, however, offer pathways for sustainable phosphorus management, including reducing input of new material to phosphorus cycling processes, reclaiming materials already in use, and finding alternatives to these resources whenever possible (Brownlie et al. 2022).

To use these pathways relies on engaging diverse groups of actors across multiple sectors and scales that are affected by society's use of phosphorus, i.e., *stakeholders*. Stakeholders are defined here as individuals or groups of individuals who can affect or are affected by an event, activity, intervention, process, and/or decision (Colvin et al. 2016; Kliskey et al. 2021). Since 2008, when an unprecedented spike in fertilizer prices shed global light on the issue of sustainable phosphorus management, a number of consortia were created to foster such engagement, often originating in scientific communities but with outreach to industry, policymakers, and other interested parties. These various—although we argue rather fragmented—initiatives have been instrumental to advancing the science, identifying research priorities, advising policy, and advocating for more attention to sustainable phosphorus solutions (Ulrich and Schnug 2013). While these initial stakeholder engagement initiatives have been critical to launching the sustainable phosphorus movement more than a decade ago, they have not included as full of a range of stakeholders that span diverse sectors or are impacted by phosphorus management as compared to what the scholarly literature on stakeholder engagement and governance of complex, wicked challenges recommends (Roloff 2008).

A review of literature describing stakeholder engagement for phosphorus sustainability indicates that previous efforts have focused primarily on engaging a range of government agents, industry actors, and academics, with much less participation from other members of civil society or historically marginalized groups (Lyon et al. 2020; Martin-Ortega et al. 2022). These marginalized groups include individuals or communities who suffer the downstream social and/or economic impacts from current phosphorus management use (e.g., water quality impairment, fertilizer access) but who lack the ability to seek redress. This missing participation can be contrasted to the scholarly literature on stakeholder engagement, including recommendations from the International Risk Governance Council (IRGC) and other organizations that have called for broader and more diverse stakeholder involvement in these complex issues that impact all of society (Renn 2015; IRGC 2017). Further, literature on best practices for stakeholder engagement emphasizes the inclusion of a range of stakeholder needs, perspectives, and viewpoints in complex problem-solving processes (Bryson 2004; Lyon et al. 2020). The recent OPF report (Brownlie et al. 2022) also advocates for developing multi-perspective transdisciplinary approaches to stakeholder engagement. The report further advocates for balancing stakeholder participation in decision-making, addressing differences in stakeholder agency, planning for uncertainty, increasing the transparency and access to phosphorus flow data, creating awareness campaigns to guide the public, and supporting *coordinated stakeholder engagement* across sectors and geographic boundaries.

Thus, building on this body of literature and including recommendations made in the OPF Report, we describe in this Perspective what coordinated stakeholder engagement could entail for phosphorus sustainability contexts. Overall, the purpose of this Perspective is to define what we describe as coordinated stakeholder engagement, to identify key process elements through examples from past sustainability efforts, and to suggest where those elements may be applied to identifying and working with stakeholders to create alignment in thought and action toward sustainable phosphorus management.

2 What is coordinated stakeholder engagement?

Stakeholder engagement entails deliberate interaction with individuals or groups who have a "stake" in an issue or resource (Reed et al. 2009). Stakeholder engagement is generally defined as structured approaches and processes to interact with stakeholders, through communication-based, consultation-based, and deliberation-based forms of engagement (Rowe and Frewer 2005; Grieger et al. 2022a). Building off the extensive body of literature related to stakeholder engagement, we identify '*coordinated* stakeholder engagement' as an approach to organizing stakeholders in a way to produce specific outcomes, such as improving sustainable problem-solving. For example, the OPF Report refers to coordination primarily in terms of intergovernmental cooperation, with some mention of institutional-level or cross-sector planning and collaboration (Brownlie et al. 2022). Other resources discuss coordination mechanisms or actions that can lead to stakeholder collaboration (Lim and Sirimanne 2011; FISPLG 2019; Makhura and Mabuza 2019).

For the purpose of a sustainability initiative such as improving phosphorus management, we define coordinated stakeholder engagement as an intentional approach to accessing diverse stakeholders in such a way that the relevant stakeholder needs and interests are represented and common challenges are identified, products of innovation are co-created, and equitable solutions are enacted in a strategic effort. The types of processes, relationships, and communication between different stakeholder perspectives as might be managed through a designated coordinating body are illustrated in Fig. 1. The intention here is to take an issue-focused approach, where the management of stakeholder coordination may originate through a particular initiative, but is centered on a specific sustainability goal, so that stakeholders are defined through their relationship with that goal. In this way, coordination "sets the stage" for buy-in and collaboration toward a mutually beneficial purpose between different groups. Coordination also provides opportunities to identify or develop common ground and common goals among diverse perspectives, improving the potential for aligning motives to support meaningful change. Further, coordination allows for the pooling of ideas, knowledge, and resources between stakeholder groups, promoting a sense of shared responsibility of perceived problems and ownership in solution spaces.

There are a number of coordinated stakeholder engagement strategies. Top-down approaches involve decision-making at higher levels and include broad international initiatives targeting specific outcomes through policy or multilateral agreements. Bottom-up approaches generally originate at a fundamental or grassroots level to achieve goals within specific or localized contexts. Efforts to integrate top-down and bottom-up strategies can be an effective way to manage large-scale initiatives or goals while acknowledging the need for context-specific approaches at more localized levels (Gaymer et al. 2014). Other strategies may involve a more informal approach, often between stakeholders from different social or economic sectors (e.g., communities, researchers, industry). These models of stakeholder coordination offer varying mechanisms of engagement or influence between stakeholders and organizations (FISPLG 2019). For example, a consultative approach may focus on information gathering or may facilitate information sharing without engaging in decision-making (Osman et al. 2018; Mitchell and Styan 2019). Conversely, a participatory decision-making approach enjoins stakeholders to collectively weigh alternatives and determine a course of action (Gray et al. 2020).

Regardless of the engagement model used, understanding and identifying who should be involved is key to a successful stakeholder coordination effort. Smith (2017) classifies stakeholder roles as either "key," "influential," or "interested," suggesting that—at least when viewed from an organizational standpoint—stakeholder engagement need not target all stakeholders all of the time. However, this paradigm overlooks what we describe as "marginalized"

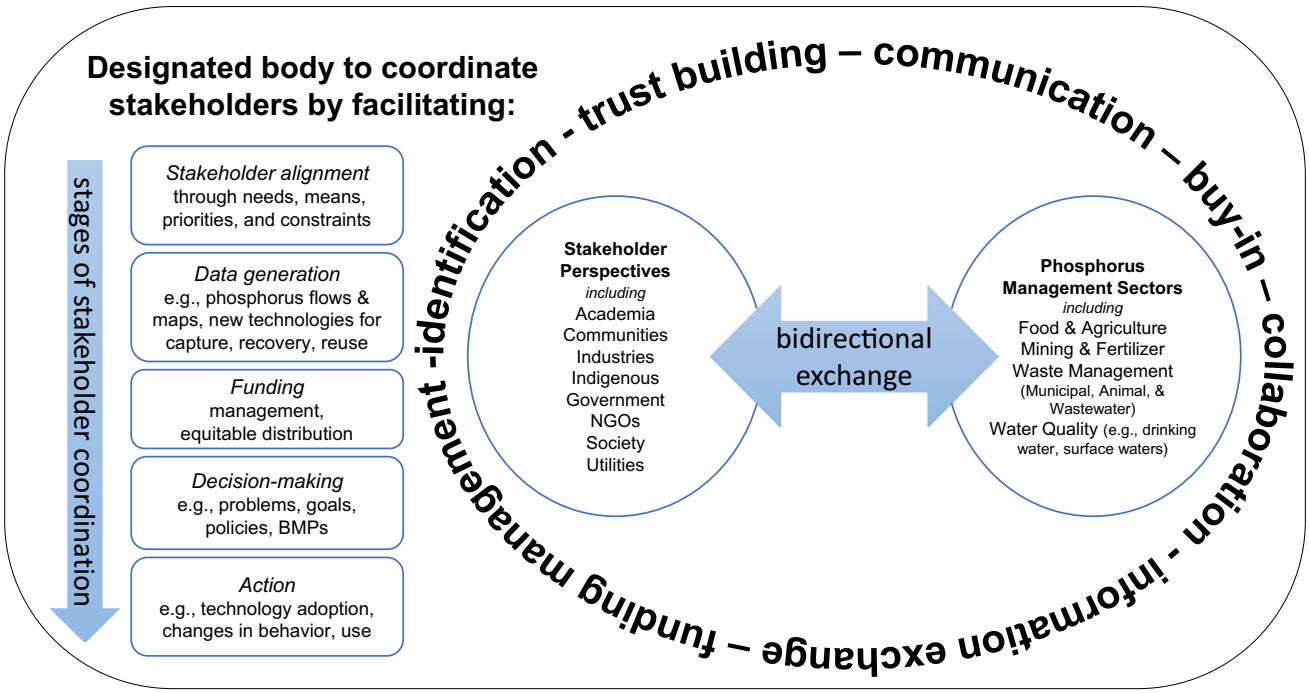

Fig. 1 Processes and interactions between stakeholder groups and a central, coordinating body to organize and conduct stakeholder engagement related to phosphorus management

stakeholders, i.e., those whose quality of life has been affected by current practices or who may be impacted by future change (Vogler et al. 2017), but who may lack influence, power, or awareness of the importance of engagement on phosphorus. Thus, it is important for researchers and others focused on sustainability issues to look beyond these roles to consider who may be left out. In other words, coordination efforts should be targeted and intentional both in terms of how to approach stakeholders based on their needs as well as the goals of the sustainability initiative (e.g., collecting information, eliciting support, adopting action). Furthermore, it is important to assess how best to engage with each type of stakeholder. For example, stakeholders may operate on different schedules and timeframes, rely on different methods of communication, and have multiple or competing interests, motivations, or priorities regarding if or how they participate. It is not enough to assume that anyone interested will be at the table. When coordinating diverse stakeholder groups there must be clarity of purpose, opportunities for feedback and discussion, and an organizational structure that ensures stakeholders will have the agency to inform the process over time with regard to research, policy direction, and change.

3 Examples of coordinated stakeholder engagement

The Montreal Protocol is perhaps one of the most well-known examples of a top-down approach to engaging stakeholders at the international level. It is a treaty coordinated with governments across the globe to regulate the production and use of chemicals that degrade the Earth's stratospheric ozone layer (one of the previously mentioned nine planetary boundaries). Ratified by all United Nations member states in 1987, the Protocol is still in effect and continues to lay out clear goals, timelines, and "equal but differentiated" responsibilities for its participants (UNEP). One of the most impactful aspects of the Montreal Protocol has been the phasing out of hydrochlorofluorocarbons that are both ozone degrading substances as well as powerful greenhouse gases. Reasons for the Protocol's success are numerous, including how its implementation managed stakeholders and their expectations through strong leadership, shared commitment, flexibility in goal setting, scientific credibility, and stability through long-term enforcement (Rae 2012). In this way, the Montreal Protocol aligned stakeholders to a well-defined environmental challenge and developed enforceable actions to mitigate that challenge. Two additional components of the Montreal treaty that help account for its success are centralized administration by the Ozone Secretariat and the establishment of a self-sustaining financial mechanism, the Multilateral Fund, to support developing countries in meeting their objectives (Ozone Secretariat 2020).

In an example of a multi-scalar coordination approach, the U.S. government convened the Hypoxia Task Force (HTF), made up of federal agencies as well as state and tribal officials in the Midwest, to address the Dead Zone in the Gulf of Mexico. This hypoxic zone is caused, in part, by nutrient loss from fertilized fields in the states along the Mississippi and Ohio Rivers, including Illinois, Iowa, and Minnesota, and thus transcends state boundaries. Now led by the Environmental Protection Agency (EPA), the HTF provides federal funds and technical support for nutrient loss reduction strategies developed by the states (US EPA 2014). In formulating these strategies, the states have pursued different paths. At the outset, Iowa state officials joined Iowa State University researchers to develop a strategy. They waited until later to work with stakeholders, which delayed implementation (Anderson and Vasto 2019). To develop its strategy, Illinois state officials from EPA, the Department of Natural Resources, and the Department of Agriculture have worked in partnership with stakeholders representing manufacturing, wastewater treatment, and environmental groups. To address nutrient loss from non-point sources, they have specifically engaged the agricultural community through advocacy organizations, commodity groups, soil and water conservation districts, contractors, and Extension (IL EPA 2021). These groups have identified best management practices on farms to address nutrient loss and have sponsored extensive outreach to convince producers to adopt those practices. In a policy arena where regulation mandating particular practices may be impossible, such coordination among state and federal officials and local stakeholders may be the most effective means of changing farming practices to achieve an overarching national goal.

Coordination can also occur at local scales and sectors through consultation and decision making with stakeholders in support of a sustainability initiative. A North Carolina State University-funded project, the "Sweetpotato Analytics for Produce Provenance and Scanning" (SweetAPPS) presents an example of coordination at a local scale by consulting with stakeholders to understand their perceptions, needs, and potential concerns in the development of new technologies for sensing and data collection (Grieger et al. 2022b). The project objective to improve the quality and utilization of sweet potato crops is designed to support a sustainability initiative to reduce food waste. To accomplish this goal, the SweetAPPS team serves as a coordinating body that identified relevant stakeholders from diverse perspectives in the North Carolina sweetpotato value chain and invited those interested to share their perspectives. The team also worked with the North Carolina Sweetpotato Commission, a local community-based organization, to improve sustainability in the industry. Finally, the team participates in community

events to facilitate and strengthen communication within the stakeholder community through information sharing and disseminating research findings as well as insights from the stakeholders themselves. By working closely with stakeholders the project has supported the development of new sensing technologies and an integrative data platform that meets both consumer and sweet potato producer needs (Grieger et al. 2022b). Overall, the Sweet-APPS project integrates a sustainability issue-focused approach with an organization-oriented focus—that of an academic research program—to managing stakeholder coordination, with the ultimate goal of reducing food waste through improved quality and utilization of sweetpotato crops. The significance of this type of stakeholder engagement is the recognition that it is not enough for researchers and technology developers to address a specific sustainability-oriented need without involving the stakeholders who are the end users of proposed solutions.

4 Barriers to coordinated stakeholder engagement

Despite successful interventions to address sustainability issues across different boundary scales, from global to local levels through coordinated stakeholder engagement, barriers to adoption and adaptation of solutions exist. The Kyoto Protocol is an example of how a top-down, international approach can easily fail, despite sharing many of the elements that made the Montreal Protocol so successful (Sunstein 2006). A key difference between the two agreements was the degree of stakeholder buy-in. Although the focus of the Kyoto Protocol was reducing greenhouse gas (GHG) emissions, there was much less agreement regarding the science or impacts related to climate change. Additionally, the Protocol excluded developing countries from compliance, while penalizing wealthier nations for noncompliance, despite their significant contributions to GHGs (Maizland 2022). Ironically, this lack of "shared responsibility," coupled with lack of public support in the United States and elsewhere, contributed to the Kyoto Protocol's failure (Sunstein 2006). Indeed, the more complex and socially embedded an issue, the more likely barriers to change will be encountered. One concern relates to priorities and timelines of who is doing the coordinating, the type of "ask" presented, and what benefit each stakeholder perceives from participation. Government agencies are subject to political agendas and cycles which can impact prioritization and commitment. Industry-related groups are typically profit-driven which is naturally exclusionary. Non-governmental organizations (NGOs) are both limited to and influenced by fundraising and public support, while academic and research institutions suffer from time lags, operating on a scale of years rather than months. Partnerships between these different sectors increases diversity but decentralizes organizational authority and the ability to coordinate between stakeholders (Makhura and Mabuza 2019).

As noted, a key challenge includes developing consensus among diverse, often disparate perspectives, which takes time and investment building relationships and trust. Still, alignment is a critical component to achieving any sustainability initiative and a primary driver for engaging in stakeholder coordination. Other barriers include managing power distribution to ensure equity, sharing data and information while also maintaining confidentiality and privacy, and funding both a sustainability initiative and, if designated, a coordinating body in perpetuity to operate without undue influence from any funding source or a loss of interest in financial support (Kuzma and Grieger 2020; Grieger et al. 2022b). Furthermore, the types of stakeholder engagement used, the stakeholders involved, and the structure of a coordinating body are dependent upon the context, scale, and scope of the sustainability initiative.

5 Applying stakeholder coordination concepts to phosphorus sustainability

When it comes to sustainable phosphorus management, a coordinated approach that both engages a diverse range of stakeholders and addresses the aforementioned barriers is essential. This will help ensure that not only are multiple needs and viewpoints considered, but also that those needs are organized, managed, and communicated in a strategic and harmonized manner to achieve a specific goal, even when there are a large number of stakeholders or substantial differences in their perspectives.

The concept of phosphorus sustainability may initially appear to be relatively straight-forward and easy to rally support around, especially given our society's reliance on this finite resource. Yet, phosphorus is inextricably linked to many aspects of society, including the economy, food production systems, and ecosystem management, as well as complex geopolitical aspects that vary across local, regional, national, and international boundary scales (Brownlie et al. 2022). Furthermore, creating a circular (bio)economy for phosphorus (i.e., closing the phosphorus loop and reducing or eliminating phosphorus "leaks") requires innovation and commitment at every step of the phosphorus value chain, from extraction to use and disposal. Thus, as previously noted, sustainable phosphorus management cannot be addressed as an isolated issue. Instead, the goal of sustainable phosphorus management should be coupled with associated issues, including nutrient management, water quality management, sustainable food production, solid waste management, and beyond. Developing an inclusive and coordinated stakeholder

engagement process for managing phosphorus sustainability should address not just society's current use of phosphorus but also the overarching motives to improve social, economic, and environmental welfare in general. These include broader goals like global food security, clean water, thriving ecosystems, and equitable access to limited resources that, like phosphorus, can have implications across many different sectors and scales.

There is extensive academic literature on the science of stakeholder engagement, public engagement with science, and both theoretical frameworks and case-studies of different engagement strategies with regard to sustainability (for example, see Hörisch et al. 2014). Additionally, policy briefs by international organizations (e.g., United Nations Network of Experts for Paperless Trade in Asia Pacific (UNNexT), Alliance for Financial Inclusion (AFI)) also provide real-world guidance on how to implement successful stakeholder coordination planning. Numerous sustainability initiatives, including those related to phosphorus management, already engage in at least some recommended practices.

In Table 1, we outline some of these important aspects with regard to developing a coordinated stakeholder engagement strategy for a phosphorus sustainability initiative. These include approaches to identifying and classifying stakeholders, coordinating engagement, acquiring stakeholder buy-in and cooperation, dealing with unanticipated events or delays, ensuring robust communication, and securing funding. While this is definitely not an exhaustive list of available strategies, they include key points that many successful sustainability initiatives have in common.

We have also noted that there is a certain fragmentation or lack of dialog between the current phosphorus sustainability initiatives or consortiums. This presents a larger opportunity for the establishment of a coordinating body to manage the process of stakeholder engagement, either within the localized context of a particular initiative or organization, or by integrating those efforts into the broader sustainability picture. Figure 1 suggests how a coordinating body would work to harmonize scientific, government, industrial, and public realms. The networks and collaborations that form through these relationships mean that over time, a successful initiative or organization might expand or merge with other phosphorus sustainability initiatives, broadening sustainable phosphorus management across scales, sectors, and stakeholder groups. Demonstrated success at a regional or national level might help lay the groundwork for a coordinated stakeholder engagement protocol for phosphorus management at an international level.

Regardless of the scale or scope from which a coordinating body originates, its primary benefit is the day-to-day management of knowledge and information sharing between different factions such that all may benefit from the experiences of each, while also protecting confidentiality, privacy, and building trust (Grieger et al. 2019; Kuzma and Grieger 2020). The coordinating body also acts to facilitate communication and alignment toward a common goal and a

Table 1 Common strategies to successful coordinated stakeholder engagement for a phosphorus sustainability initiative (adapted from FISPLG 2019; Watson 2007)

Engagement aspect	Management strategy
Stakeholder identification/classification	Determine the stakeholder groups relevant to sustainable phosphorus management as those who affect or are affected by stakeholder management. Figure 1 suggests some key sectors and perspectives related to sustainable phosphorus management
Coordinated administration	Designate a coordinating body or institution whose function is to work with multiple stakeholders, potentially across different boundary scales to achieve sustainable phosphorus use and management
Stakeholder buy-in and cooperation	Engage in open, transparent, frequent communication to provide opportunities to voice concerns, address emergent sustainability issues, and convey awareness of the value of contributions to success. Engagement opportunities that align perspectives and build trust include science-based policy advice across all levels of leadership and regulation, accessible forums for inclusive stakeholder discourse (e.g., town hall meetings), targeted outreach programs, and annual progress reporting among others
Unanticipated events or delays	Build flexibility, adaptability, and resilience into objectives and timelines with a mechanism for managing change. This includes short and long-term planning that addresses both natural disaster and societal disruptions (e.g., economic) with clear acknowledgement of potentially affected parties
Communication	Develop a formal communication plan for all stakeholders to determine when and how information should be exchanged and the appropriate channels for engagement and feedback. Incorporates intentional early and ongoing stakeholder and community engagement that leverages existing communication channels across sectors and boundary scales
Funding	Identify a mechanism for collect, budgeting, and distributing funds to sustain the coordinating body as well as provide support for stakeholders' ability to achieve targeted goals. Potential funding sources include grants, institutional support, member contributions, government resources, or a combination thereof

shared sense of purpose among participants. Providing the coordinating body with operational autonomy, even within an individual organization, will help ensure fairness to all stakeholder groups, which is particularly important when diverse or conflicting perspectives are involved. However, depending on the scale and scope of the phosphorus management goals, the coordinating body might still operate from within the organization sponsoring the sustainability initiative, such as an academic institution, NGO, or governmental agency. Alternatively, a coordinating body may be created as an independent entity through the support of a consortia of stakeholders. For an existing phosphorus sustainability initiative that already has recognized expertise, established funding sources, and an expansive network of relevant stakeholders (e.g., the Science and Technologies for Phosphorus Sustainability Center or the Sustainable Phosphorus Alliance) (STEPS 2021; SPA), designating a coordinating body could facilitate achieving their ambitious visions.

Like the sustainability initiative itself, to guarantee its long-term viability the coordinating body also requires sustained funding. Again, depending on the particular context, this may come from external sources (e.g., grants or endowment funds) or internal sources (e.g., institutional support, including funding at the federal government level), or a member-supported stakeholder cooperative. In any case, the coordinating body would need to maintain independence from undue influence of any stakeholder irrespective of contribution to ensure equitable distribution of resources and to provide assistance as needed to groups who lack the resources to support their own efforts.

6 Concluding remarks

There is a demonstrated need for more sustainable phosphorus management to help ensure the long-term prosperity of society and the natural environment. Although a number of organizations and initiatives have been created to begin addressing this critical challenge, a more coordinated approach and aggregation of these efforts could improve the effectiveness and efficiency of their observed outcomes, reduce lag in communications and increase the inclusion of historically marginalized or omitted stakeholder groups. Literature and policy initiatives have demonstrated that a dedicated and independent coordinating agency is a particularly effective approach for organizing stakeholder coordination, particularly across multiple sectors, groups, and boundary scales. Additional strategies include establishing a communal funding mechanism, creating a communication plan to ensure open timely stakeholder engagement to facilitate trust and collaboration, and building in flexibility and adaptability in the coordination plan to account for change from both intentional activities and unanticipated events. It is important to recognize that the intricacies and complexities of pursuing a sustainability challenge both complicates but also increases the need for stakeholder coordination, cooperation, and collaboration. Sustainable phosphorus management goals do not exist independently of other critical social and environmental sustainability initiatives such as nitrogen cycling, water quality management, or agricultural production. Therefore, coordinating with stakeholders across multiple boundary scales and initiatives for phosphorus management will also help integrate this particular sustainability goal with other social and environmental sustainability targets for mutually successful outcomes.

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Declarations

Competing interest Alison Deviney, Khara Grieger, Ashton Merck, John Classen, Anna-Maria Marshall have no competing interests to declare that are relevant to the content of this article.

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