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Towards phosphorus sustainability in North America: A model for transformational change

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A B S T R A C T

Global food production and security rely heavily on finite reserves of newly mined phosphate for fertilizers. However, systemic inefficiencies result in the deposition in aquatic ecosystems of much of the phosphorus mined for food production causing costly eutrophication problems that damage aquatic ecosystems and human health. The Sustainable Phosphorus Alliance (SPA, formerly named North American Partnership for Phosphorus Sustainability) was created to implement sustainable phosphorus solutions through active engagement of stakeholders in both the private and public sectors. This paper describes a conceptual model of transformative change to a sustainable phosphorus system for the North American region. The model emerged from discussions at a series of formal and informal meetings held in conjunction with a 'Future of Phosphorus' event (National Science Foundation's Phosphorus Sustainability Research Coordination Network) and an inaugural SPA Board meeting. Model development drew on the multi-level perspective of socio-technical transitions to develop a series of pathways to a transformed phosphorus system. The uses of the model and transition pathways are discussed in terms of their potential to form an important first step towards the development of a regional vision for improved phosphorus sustainability. The process provides an example of how research in sustainability science can contribute to action on environmental improvement.

1. Introduction

1.1. Background

The world's food production has relied heavily on finite reserves of phosphate for fertilizers for over half a century. In 1979, a Report to the US Congress called for action on long-term phosphorus security in the United States, recommending that "*the highest level of government begin promptly an assessment of access impediments to phosphate minerals and review the Nation's long-range phosphate position regarding future availability, including legislative changes as may be needed to ensure supply*" (US GAO, 1979). Although little action has taken place in the 37 years since then, there have been several discrete events in recent years that have raised widespread consciousness of the phosphorus challenge. For example, in 2008, a global price spike in phosphorus triggered by rising biofuel demand and high agricultural commodity prices resulted in phosphate fertilizer demand temporarily exceeding supply, leading to farmer riots and suicides, and creating a sudden increased awareness in the longer-term vulnerability of our food systems to phosphorus scarcity (Cordell et al., 2015; de Ridder et al., 2012). While the Great Lakes of North America have experienced persistent summer algal blooms, in 2014, a severe algal bloom caused in part by agricultural phosphorus runoff threatened drinking water for a town of 400,000 people (Brooks et al., 2016; Pick, 2016). Environmental problems associated with phosphorus persist, despite ongoing changes in agri-environmental policy consistent with ecological modernisation in US agriculture that include incorporation of environmental protection technologies into agricultural production practices and a greater focus on local governance, (Reimer, 2015).

In 2011 the U.S. National Science Foundation funded the Phosphorus Sustainability Research Coordination Network (P RCN) to identify solutions for phosphorus sustainability by catalysing an interdisciplinary synthesis of data, perspectives, and understanding about phosphorus. The phosphorus RCN has three principal aims[1]:

1 Coordinate and integrate disconnected geological, agronomic, biogeochemical, economic, and sociological data and perspectives related to phosphorus sustainability;

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[1] https://sustainablep.asu.edu/about

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2 Design and assess institutional, commercial, technological, and psychological solutions in conservation, recycling, and equitable distribution to establish phosphorus sustainability;
3 Engage policy makers to bridge the gap between understanding and enacting solutions.

In early 2014, participants at the P RCN proposed to create the North American Partnership for Phosphorus Sustainability (subsequently renamed the Sustainable Phosphorus Alliance) to implement sustainable phosphorus solutions. The goal of SPA is to actively engage stakeholders (e.g. national and local policy makers, planners and officials, representatives of agriculture, and industry) to promote and foster the implementation of sustainable phosphorus solutions in both the private and public sectors. This paper describes the development of a collective vision and high-level strategy for a transformed sustainable phosphorus system in North America. We believe that a strategic approach to phosphorus sustainability involving multiple actors, sectors and disciplines, is an essential enabling capacity for supporting practical implementation of local management action over the extended timeframes and in the dynamic contexts (Patterson et al., 2013) that will be required to achieve system-wide change.

1.2. The phosphorus challenge: a wicked problem

The achievement of sustainable use of phosphorus can be classified as a wicked problem, that is the issue is complex, open-ended, intractable, and contested (Head, 2008). Such problems are characterized by high levels of uncertainty as to the nature and extent of the risks involved for individuals and society as a whole and typically sit at the interface of social and natural systems (van Beuren et al., 2003). Solutions to such problems are thought to lie in collective action by multiple stakeholders and are therefore heavily reliant on the construction and maintenance of social capital (Stoll et al., 2015), which in turn requires new process responses, such as coordinated government, cross-sectoral collaboration, mediation and conflict reduction processes (Head, 2008). The establishment of SPA can be viewed as an attempt to create the social capital (Adler and Kwon, 2002) needed to address phosphorus sustainability at a regional scale.

Agricultural demand over the last 75 years has increased global phosphorus mobilization four-fold (Falkowski et al., 2000; Villalba et al., 2008). This timeframe corresponds to the much-touted “Green Revolution” that enabled a doubling in global human population. Much of the phosphorus we have mined for food production, however, has ended up in aquatic ecosystems, causing costly eutrophication problems (Bennett et al., 2001; Smith and Schindler 2009, Sharpley et al., 2013). The fundamental problem is that inefficiencies and large losses of phosphorus occur at all points in food production (Withers et al., 2014) These losses are so great that only one-fifth of the phosphorus mined specifically for food production is incorporated into the food consumed by the global population (Cordell et al., 2009). This linear flow means lost phosphorus often enters the environment and is replaced with newly mined material rather than being recovered and recycled. In contrast, most natural ecosystems cycle phosphorus tightly and conservatively (Smil, 2000). The world's dependence on mined phosphate for food production creates a serious threat to food security because concentrated sources of phosphate are finite. Estimates of demand exceeding the supply of high-grade reserves range from 20 to 70 years (Cordell and White, 2011; Mohr & Evans, 2013; Ward, 2008). While attention was focused on ‘physical scarcity’ during the phosphorus price spikes of 2008, the economic, social, institutional, and political challenges associated with global phosphorus supplies will likely begin well before mineral phosphorus reserves “run out” (Vaccari, 2011; Cordell & White, 2014; Elser and Bennett, 2011). These challenges will be unprecedented because unlike other scarce minerals and metals, there is no technological or biological substitute for phosphorus.[2]

The Food and Agriculture Organization (FAO) defines food security as the condition in which “all people, all the time, have access to sufficient, safe, and nutritious food to meet their dietary needs for an active and healthy life” (FAO, 2006). The economic challenges of expensive phosphorus will disproportionately affect food production in countries that are heavily reliant on phosphorus fertilizer imports; are politically conflicted with mineral phosphorus exporters; and/or are relatively less affluent with low capacity to adapt (Cordell and Neset, 2014; HCSS, 2012). In developed countries where most phosphorus consumption takes place only about 20% of grocery-store food costs are actual “farm costs” (including fertilizer) (Childers et al., 2011). As a result, the market signals of phosphorus scarcity will be weaker and traditional market forces (e.g., food prices) will be slow to drive phosphorus conservation. Phosphorus commodity prices declined rapidly after the 2008 price spike but have subsequently begun to escalate: phosphate rock prices are currently two- to three-times higher than they were in 2007 (Mew, 2016). While the 2008 crisis was a temporary supply shortage, it demonstrates the serious consequences of even a short-term supply disruption and attendant price fluctuations (Cordell & White, 2014).

The stocks, flows and governance of phosphorus in North America can be conceptualised as a complex, dynamic system that evolves (Mittlelton-Kelly, 2003) in response to a range of internal and external drivers (Frantzeskaki and de Haan, 2009). Achieving sustainability in such systems requires multiple often inter-related transitions in technology, markets, human behaviour, policy and culture (Geels, 2004). Much of the discourse around phosphorus sustainability has taken place in the social-ecological resilience literature because it has centred on the environmental impacts, particularly in aquatic ecosystems, of the management of phosphorus (e.g. Bennett et al., 2001; Carpenter et al., 1998; Carpenter, 2005; Folke et al., 2004; Gunderson 2003; Sharpley et al., 1994; Walker et al., 2004; Millennium Ecosystem Assessment, 2005). However, because improved phosphorus management is dependent on technical innovations in the extraction, processing, formulation and application of P, the socio-technical transitions literature also provides a framework for examining the complexity of such multi-dimensional change (Geels, 2010). There is considerable overlap, and some tension, between socio-technical and social-ecological approaches (Smith and Stirling, 2008). The tension occurs because technological change does not necessarily enhance social-ecological resilience (Smith and Stirling, 2010). For example, increased intensification of agriculture if not carefully managed can lead to greater productivity benefits, but also increased environmental pollution as a consequence. However, in seeking technical transitions to improved phosphorus sustainability, we contend that it is essential such solutions contribute to, or at worst do not further erode, social-ecological resilience.

2. A model for transformative change

The model presented in this paper draws on theories of transition management (Geels, 2002) and the economics of increasing returns (Arthur, 1989). The multi-level perspective of socio-technical transitions views systems as consisting of niches, regimes and landscapes (Smith et al., 2010). Fig. 1 illustrates these components of socio-technical systems as a conceptual model used later in our workshop process. Landscapes form the context or environment within which the social system co-evolves with technology with (Frantzeskaki and de Haan, 2009):

- *Business-as-usual*: represented as the regime or the dominant functioning of the system (or in this case, the current state of phosphorus sustainability in North America).

[2] Phosphorus, nitrogen and potassium are all essential macro-nutrients for food production, however nitrogen can be fixed from the atmosphere by plants, and potassium resources (mined potash) are not as scarce as mined phosphate.