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P-FUTURES: towards urban food & water security through collaborative design and impact

David M Iwaniec[1,3], Geneviève S Metson[2,3] and Dana Cordell[2]

Phosphorus is essential to food production, but current management practices fail to ensure equitable access to farmers globally and often results in polluted waterways. There is a lack of local and global governance mechanisms to ensure phosphorus is sustainably managed. The P-FUTURES research initiative aims to address this gap by working with stakeholders to explore visions and pathways of social transformation towards food and water security. In the seed phase of the project, academic, civil, industry, and municipal stakeholders interacted as partners in Blantyre (Malawi), Hanoi (Vietnam), Sydney (Australia), and Phoenix (USA) to collaboratively develop a full proposal and build capacity for transformational change. The article offers guidance on the opportunities and challenges of co-developing a research approach and proposal in a transdisciplinary, international setting.

Addresses
[1] Julie Ann Wrigley Global Institute of Sustainability, Arizona State University, Tempe, AZ 85287-5402, USA
[2] Institute for Sustainable Futures, University of Technology Sydney, PO Box 123, Broadway, NSW 2007, Australia

Corresponding authors: Iwaniec, David M (david.iwaniec@asu.edu), Metson, Geneviève S (genevieve.metson@wsu.edu)
[3] These authors lead the manuscript and contributed equality to this work and as such are co-first-authors.

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The phosphorus challenge

Human consumption of phosphorus for food production and industrial uses has increased over fivefold since the 1960s [1], making human activities the driving force of phosphorus flows on the planet [2–6]. Sustainable phosphorus management has been recently emphasized as an essential component to meet UN global food security and water quality objectives [7]. Without access to phosphorus, farmers and nations will not be able to produce sufficient food, yet there are no effective governance mechanisms in place to ensure long-term access to the resource or to stimulate sustainable phosphorus practices [8••,9]. Remaining reserves are non-renewable, unevenly distributed, and becoming increasingly scarce and expensive; nearly one billion of the world's poorest farmers are unable to access fertilizer markets [9]. At the same time, losses of phosphorus along the food chain, from runoff and soil erosion from fields, all the way to human and animal excreta and urban food waste, contribute to widespread water pollution [10]. Phosphorus losses to waterways lead to eutrophication [11,12], which in turn can cause toxic algal and cyanobacterial blooms (affecting drinking water supply) and hypoxic zones [13–16].

Cities can be catalysts for larger scale change through their strong political and economic influence and are crucial centres for decision-making and innovation (as seen with global change [17], and specifically climate change [18]). As such, urban areas could be key agents in responding to the global phosphorus challenge because cities are 'phosphorus hotspots', that is, cities concentrate people, and by doing so concentrate both the demand for food and the generation of phosphorus-rich organic waste [19–21]. For example, cities are being reimagined as closed loop systems where phosphorus in waste streams become resource opportunities for urban and peri-urban agriculture [22–24]. Urban environments therefore represent both the scarcity and pollution sides of the phosphorus challenge and potential solutions.

Local interventions to address scarcity and pollution aspects of the phosphorus challenge have often had unintended consequences. For example, fertilizer subsidies in India, to increase access to farmers, unintentionally created a black-market for fertilizers in Nepal — distorting local markets [25,26]. In the USA, Lake Erie initially saw decreases in harmful algal blooms with the application of a suite of changes in local farming practices and increased treatment of urban wastewater. However, unintended interactions between national energy policies, the selection of 'best management practices' such as no-till agriculture, and climate change effects have resulted in the re-emergence of the algal blooms [27]. We use these examples to demonstrate that addressing individual causes of local scarcity or pollution separately may not be sufficient to address phosphorus sustainability challenges. It is not enough to trust that uncoordinated, incremental knowledge and actions will be sufficient to solve these challenges.

Food and water security will need to entail transformative outcomes in phosphorus sustainability, including explicit

consideration of global and local resource governance, human well-being and livelihoods, and account for the persistent and growing challenges of inequity, urbanization, and climate change [28,29].

Transdisciplinary gap to move towards phosphorus social transformations

Scientists have made great strides in understanding the biophysical and technical dimensions of the phosphorus challenge (e.g. [30–32]), but these strides have not resulted in the large-scale transformations needed to ensure global (or even local) food security and clean water. There is an increasing awareness that this inaction is related to gaps in knowledge around the social dimensions of the phosphorus challenge and how this knowledge is integrated into decision-making [20••,33]. In particular, different geographical regions and actors are vulnerable to phosphorus scarcity and pollution in different ways [9], and therefore governance strategies must be locally adapted.

Substance flow analyses has been the dominant tool to understand the movement and storage of phosphorus and to help decision makers improve phosphorus management [19,20••]. However such studies have rarely resulted in significant changes, in part because they lack explicit inclusion of the unique context-specific environmental, governance, and institutional drivers of phosphorus access and use [9,20••]. For example, Kalmykova *et al.* [34] and Gumbo [35] note that the cultural acceptance of waste reuse could be a barrier to increasing phosphorus recycling, however was not within the scope of their quantitative studies. The cross-scalar nature of the phosphorus challenge from global to local [9] and past to future is also a key barrier to transformation [23]. Infrastructure lock-ins and governance legacies constrain the types of solutions that are available to cities [36–38]. Similarly, MacDonald *et al.* [39] demonstrate how global trade and national farming and energy policies affect local farming phosphorus flows in the USA and are a socio-political barrier to change. In fact, phosphorus management is linked to both national and urban sustainability and resilience priorities (e.g. food, water, energy, poverty alleviation, and ecosystem integrity). However, these linkages are often not made explicit [20••,40•,41,42].

In order to address these knowledge gaps and to create 'on the ground' change, there is a need to integrate local stakeholder knowledges specifically through co-production processes [43•,44,45••]. Moving beyond engineering technical solutions towards co-developing social-ecological–technological transformations that affect how we use and govern this resource are necessary [9,20••].

P-FUTURES seed phase approach

P-FUTURES is a cross-city initiative designed to address phosphorus security challenges and opportunities, funded by the International Social Science Council (ISSC) Transformations to Sustainability programme. P-FUTURES aims to co-create the foundations for transformative change on a trajectory towards food security and water resource integrity. The seed phase (6 months) was designed to create relationships among stakeholders and researchers across cities and design a research approach to social transformations that would be viable for a 3 year project. This phase focused on four cities: Hanoi (Vietnam), Blantyre (Malawi), Sydney (Australia), and Phoenix (USA). The existence of sufficient available phosphorus information and existing research contacts, keen to participate, influenced city selection. We selected these cities to span a wide range of socio-economic and biophysical conditions in order to explore a more comprehensive range of governance, institutional, and social arrangements, as well as technological strategies than can be used in creating sustainable phosphorus pathways.

In contrast to uncoordinated, incremental knowledge and actions, deliberate social visions and implementation pathways for sustainable transformations are needed. This requires reframing research-practice approaches for how and who addresses these challenges [46], as well as defining clear intended outcomes (knowledge, situation, and mutual-learning) from the onset of the transdisciplinary research approach [45••]. In line with Midgley [47] and other soft systems theorists and practitioners, the P-FUTURES team aims for an ethical commitment to creating change through a participatory and reflexive systemic inquiry. As such the seed phase research approach focused on building capacity towards deliberate transformative social changes that: firstly, enhance equity, well-being, and livelihood, secondly, avoid environmental degradation, and thirdly, avoid unintended consequences [46,48]. We draw from transdisciplinary research in sustainability science [43•,49], adaptive capacity and learning [50–51], future desirable pathways [52–54], and transition management [55–56]. The co-production framework [43•,44,45••] was to: firstly, share and understand who, what, and how relevant actors, system features, and existing priorities interact with phosphorus, and to identify relationships and common goals, secondly, understand (and to an extent experience) each city's specific vulnerability to global, regional, and local aspects of the phosphorus challenge, thirdly, develop participatory visions and pathways for sustainable food and water systems, and fourthly, assess the participants' envisioned implementation strategies. The seed phase was used to carry-out experiential learning and workshop activities to build this capacity among stakeholders and researchers in order to refine and deepen the co-production approach put forth in the full proposal (Figure 1).

Experiential learning included stakeholder visits to urban and peri-urban farms and gardens, landfills and composting facilities, wastewater treatment plants, chemical