Introduction to P Sustainability: P is for Philosophy and Process

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Book Chapter

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Introduction to P Sustainability

P IS FOR PHILOSOPHY AND PROCESS

Genevieve S. Metson, Karl A. Wyant, Daniel L. Childers

Blake McConnell; *The P-Town Constellations*; Digital media various sizes

Blake McConnell

The P-Town Constellations

Scientific Collaborator:

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Description of Artwork:

The Ptown Constellations create a dynamic portrait of a theoretical world, like our own, facing a shortage of usable phosphorus. This compound, essential to agriculture, food production, and the fabrication of many materials, lies at the center of a growing debate about sustainable practices as they relate to economic and political priorities. Inspired by the PlanPHX visioning process, these constellations, while introducing the user to different types of sustainability strategies at different parts along the human phosphorus cycle, allows them to rank phosphorus conservation methods and see how resulting consequences compare to each other. Through interaction, they learn about phosphorus conservation issues and how personal, political, and economic choices affect others.

Users rank conservation methods using a physical game board, choosing from five choices represented in an LCD projection onto a table—investment in mining technology, phosphorus taxation, reduction of demand through consumer choices, genetic engineering, and closing the loop through recycling. Icons in a second display—representing increased cost, environmental pollution, political fallout, and even unknown consequences—portray the intensity of potential consequences to the user's ranking by growing or receding from view. This feedback alerts the user to consequences beyond phosphorus scarcity, allowing them to experiment with different strategies and resulting outcomes in pursuance of a normative state.

Each conservation method and consequence is represented by an icon. These icons, “sampled” from ancient Celtic artifacts and “hacked” using contemporary photo doctoring techniques, incorporate a design aesthetic that emphasizes interconnectedness. Mirroring the complexity of the human/phosphorus cycle, Celtic knots connect in unexpected ways, requiring close inspection to perceive their true path. These images, which reference human and animal forms, also recall patterns attributed to clusters of stars. Whereas our ancestors saw figures emerge from points in the night sky, we see them arise from our complex resource extraction and allocation systems. Do these figures appear as angels or monsters? The Ptown Constellations let the viewer decide.

About the Artist:

Blake McConnell is a media artist, musician, and activist. Originally from the Atlanta suburb of Marietta, Georgia, and a longtime resident of San Francisco, California, he now resides in Phoenix, Arizona. His creative work manifests in various ways, though the intersection of media, technology, and society serves as its fulcrum. The confluence of the implications of form and the infinite variation of perception fuel his inquiry. Inspired by years of local organizing, he embraces the frontiers of new media while respecting their incumbent responsibilities.

BOX 1.1

CHAPTER 1 OBJECTIVES

- Illustrate and explain the basic principles of sustainability.
- Apply a sustainability framework to existing issues in P management.
- Summarize human impacts on natural P cycling and the identification of P sustainability as a “wicked problem.”
- Describe how a sustainability perspective contributes to shaping appropriate solutions to P management.
- Describe the general approach of upcoming book chapters in connecting various aspects of human use of P to a sustainability framework.
- Apply a sustainability framework to existing issues in P management.
- Summarize human impacts on natural P cycling and the identification of P sustainability as a “wicked problem.”
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INTRODUCTION

The dynamics of natural resources, whether water, oil, or nutrients, can be difficult to explain, as well as manage. Natural cycling is layered with social and economic dynamics and the result can be quite complex, and exhibit a lot of spatial and temporal heterogeneity. Phosphorus (P) is no exception. Although complex, it is clear that current dynamics and P-use patterns are problematic. In fact we rarely directly manage P resources; instead we manage fertilizer, crop production, and water, which in turn affect P cycling. In this chapter, and throughout this book, we will bridge our current segmented way of viewing anthropogenic P cycling (e.g., mining, fertilizer, crop production, food consumption, and waste management) and systems-thinking view of sustainability. In this way, we hope to move toward solving challenges of current unsustainable P-use. In this chapter we will explain 1) what sustainability science is, 2) why the current state of P cycling is a sustainability challenge, 3) how we got to the current state of P cycling, and 4) how sustainability science frames the type of solutions we should consider when trying to change P cycling for the better.

A PRIMER ON SUSTAINABILITY SCIENCE

Many scientists and policy makers have recognized that traditional discipline-focused views of the world and of solving problems are no longer adequate for either

A) Conventional problem-solving framework

B) Sustainability problem-solving framework

understanding or deriving solutions to complex problems (Figure 1.1, Funtowicz and Ravetz 1993). In many ways, **sustainability*** science is a response to increasing awareness about negative **externalities*** arising from the management of resources (and services) for a single goal, often developed by a single discipline. For example, clear-cutting forests may be the most efficient means to exploit that resource for timber production. However, there are unintended consequences to such a practice that affect society immediately, such as landslides and water pollution, as well as those that affect future generations, such as the eventual depletion of forest resources for future use. Indeed, the classic “Tragedy of the Commons” (Harding 1968) demonstrates pitfalls of linear thinking, where a focus only on narrow, often individual benefits, comes at the cost of the group.

The idea of “sustainability” began to formally emerge in the early 1970s with the publication of the Stockholm Declaration on the Human Environment, which led to the creation of the United Nations Environment Programme (UNEP, Declaration of the United Nations Conference on the Human Environment 1972). The UNEP sought to reconcile the desire for economic development and maintaining environmental protection (Dresner 2002). Fast-forward to the late 1970s, which brought the concept of a “sustainable society” founded on equity and participation in the democratic process. These ideas formed the cornerstone of “Our Common Future” (Brundtland 1987), also known as the Brundtland Report, which formally defined the term sustainability. This influential report set the stage for the modern field of sustainability science. Further developments throughout the 1990s included the Earth Summit I (1992) and II (1997) and the Kyoto Protocol (Dresner 2008). According to Agyeman et al. (2003), sustainability considers “the need to

FIGURE 1.1 Contrast between approaches and solutions when using a conventional problem-solving framework (A) vs. a sustainability problem-solving framework (B). (A) The system state is the current way a system works (which could be bounded by place, by sector, or by theme). If a challenge (or problem) is identified by one type of stakeholder and, when we use a linear approach to solving this challenge we will come up with one solution to that problem. This solution, however, only addresses instead a specific problem and may have missed the complex interactions that system state exhibited. This solution may thus only work for a short amount of time, and also result in a multitude of negative consequences. The link between the unintended consequences and the intervention may be missed, resulting in the same linear method to be applied to “new” challenges. (B) On the other hand, if multiple stakeholders participate in characterizing the system state and identify challenges their diverse perspectives can result in a more complete understanding of the challenge. This “sustainability lens” is really the multiple perspectives of stakeholders coming together. This framework will result in solutions that may be more appropriate to minimize negative consequences and maximize the number of benefits from the changes. In this way, the solutions are more long-term (hence the longer time arrow). Still, there may be unintended negative consequences. However, the system’s perspective will ensure that linkages are understood and new solutions are found through an iterative process. Based on ideas and methods further developed in Scholz et al. (2006) and Robert et al. (2002).

ensure a better quality of life for all, now and into the future, in a just and equitable manner, whilst living within the limits of supporting ecosystems.” The definition of, and methods applied in, sustainability are continually evolving. However, we believe Agyeman’s definition represents the overarching themes of both sustainability science and sustainable development.

In order to understand complex social-ecological problems, and embrace sustainable development principles in our solutions, we must include and integrate the environmental, social, and economic components of a problem or challenge. A simple visualization of this is with three concentric spheres (Figure 1.2). The environment sphere is the all-encompassing life-support system upon which humans (and all other species) depend and is the largest of the three spheres. That said, sustainability is ultimately an anthropocentric concept where we aim to equitably support current and future human populations. Thus, society is an essential consideration in sustainability, including societal interactions with the larger environment and among people. Thus, the society sphere is within the environment sphere. The economy is a human construct, the tool by which societies manage many interactions (between people and nature, and among people), and is thus a sub-sphere of the societal domain. Because sustainability problems are complex, focusing on less than all three of these spheres is inadequate and inevitably produces simplistic and ineffective solutions (Figure 1.1a).

Sustainability researchers strive to understand social (sometimes social-economic) and environmental interactions, particularly the key feedbacks in **social-ecological systems*** (Kates et al. 2001, Sarewitz et al. 2010). Only by understanding these feedback dynamics can we intervene effectively to mitigate harmful effects and foster beneficial outcomes. Sustainability scientists also aim to participate in decision-making processes, as opposed to simply providing information to decision makers. Gibson (2006) proposed eight criteria to assess the sustainability of a system (Table 1.1), and these criteria can be used to identify the kinds of problems that sustainability research and practice are best suited to tackle. Problems that fit these criteria are complex, urgent, exhibit long-term dynamics, involve cross-sectoral and cross-scalar interactions, and often have solutions that are place-based; sustainability researchers refer to these as “**wicked problems***” (Conklin 2006).

FRAMING P-USE AS A SUSTAINABILITY CHALLENGE

In this book we suggest that P-use is one of the wicked problems for which a sustainability science “lens” is appropriate. This is because P cycling is involved in the provision of basic human needs such as sufficient food and clean water. The environmental stewardship necessary to satisfy these needs in the long term necessitates a

TABLE 1.1
SUSTAINABILITY ASSESSMENT CRITERIA MODIFIED FROM GIBSON (2006) THAT IDENTIFY THE TYPES OF PROBLEMS SUSTAINABILITY IS BEST SUITED TO TACKLE (I.E., SYSTEMS WHERE MANY OF THESE CRITERIA ARE NOT MET OR PROBLEMS THAT AFFECT THESE CRITERIA FOR GLOBAL AND LOCAL SOCIETIES) AND THE CHARACTERISTICS OF SOLUTIONS THAT SHOULD BE CONSIDERED (I.E., SOLUTIONS THAT SUPPORT ENVIRONMENT, SOCIETY, AND ECONOMY TOGETHER).

Sustainability Criterion	Definition	How Criterion Applies to P-Use and Related Chapter in This Book
Socio-ecological integrity	Supports socio-ecological interactions that conserve irreplaceable life-support systems	Eutrophication caused by P-use is threatening water quality (ch. 2 and ch. 5).
Livelihood sufficiency and opportunity	Ensures universal access to resources (natural and societal) needed to live a healthy and fulfilling life	Current access to P as fertilizer is unequal around the globe and farmers in poor countries do not have access to enough fertilizer to grow enough food to feed local populations and have a livelihood (ch. 3, ch. 4, and ch. 8).
Intragenerational equity	Supports equity in the capacity and opportunities regardless of economic status	There are large gaps between access to food and sanitation infrastructure between rich and poor communities. These gaps dramatically alter how specific places contribute to P requirements and pollution (ch. 7).
Intergenerational equity	Ensures equity in the capacity and opportunities between current and future generations	Our currently intensive use of mineral P and lack of alternative recycling infrastructure makes future generations extremely vulnerable to P-price fluctuations and scarcity (ch. 9).

(Continued)

TABLE 1.1 (Continued)

Sustainability Criterion	Definition	How Criterion Applies to P-Use and Related Chapter in This Book
Resource maintenance and efficiency	Maintains long-term integrity of life support systems (the biosphere)	Current use of P degrades coastal and lake environments, which are essential to regional ecosystem function (ch. 5),
Socio-ecological civility and democratic governance	Creates governance systems that support collective and responsive decision making	There is a lack of collective governance both between steps in human P-use (i.e., mining to food to waste) and across the globe to manage P resources (ch. 6).
Precaution and adaptation	Avoids decisions that may have irreversible consequences while embracing uncertainty with nimble and adaptive processes	Current mining of P and ultimate dispersal of the resource in ocean waters depletes mineral resources and prohibits P recovery downstream (ch. 3 and ch. 6).
Immediate and long-term integration	Supports interventions that mutually benefit today's and future needs and desires	Today's intensive use of non-renewable P resources puts the current benefit of the few over the benefit of food security and clean environment for future generations (ch. 9).

judicial and systematic management of P resources. In other words, P-use entails all eight of Gibson's sustainability criteria (2006). Current use of P as a non-renewable resource and current price structures prevent effective responses to P scarcity (see chapters 3 and 8) and P pollution (see chapters 2 and 4). Subsidization of P fertilizers (chapter 8), unequal distribution of P demand and P availability (chapters 2, 4, and 8), the essential role of P in food security (chapter 8), and the economic externalization of P pollution effects on aquatic ecosystems (chapter 2) all point to the clear conclusion that current approaches to P resources and P-use is inadequate, even failed. Unless we radically change how humanity impinges on global cycling of P, the problems will only worsen. In this section we will divide the P-use situation into selected environmental, social, and economic components to illustrate various connections to sustainability theory (we have also italicized key concepts brought up in both Gibson's sustainability criteria and the conceptualization of a "wicked problem").

FIGURE 1.2 Phosphorus dynamics in relation to sustainability thinking. The image illustrates the three large considerations of sustainability: environment (light gray sphere), society (dark gray sphere), and economy (black sphere) as a nested model where environment encompasses society, and economy as part of society. Words in each sphere are elements that contribute to the phosphorus use problem.

Environment

There are no substitutes for P; it is biologically essential and is thus a necessary component of the *life-support system* that is our biosphere (chapter 2). Phosphorus is essential to human society (food and the production of other goods) as well as to all other species and the ecosystems that provide services to humans. Geological processes cycle P on *long time-scales* and this has led to the unequal distribution of concentrated mineral P deposits around the globe (chapter 3). Plant-available P is also unequally distributed across the globe because of different soil characteristics (chapters 2, 4, and 5, Cordell et al. 2009). The environment is also the recipient of the downstream consequences of inefficient and wasteful human uses of P (chapter 2). Impacts include the eutrophication of fresh and coastal water bodies (algal blooms that severely degrade water quality), as well as mining pollution (chapters 2, 3, and 5). These negative consequences have direct effects on people and economies by impairing various ecosystem services, including provision of safe drinking water, food provisioning through fisheries, as well as recreational amenities and habitat quality.

Society

Cultural norms and local biophysical characteristics of a region make both the problems (chapter 5) and the solutions (chapters 6 and 7) to P-use specific to a *particular time and place*. How different societies produce food, alter landscapes, choose their diet (especially vegetarian vs. meat intensive), and manage their wastes shapes their effects on the **human P cycle*** (per Childers et al. 2011). Interestingly, only about 20 percent of all P used to produce food is actually consumed in food—the remaining 80 percent is lost to inefficiencies and waste in the human P cycle (Childers et al. 2011). Beyond farm losses of P (which are explored in chapter 5), about 55 percent of the P in food is lost to inefficiencies “between farm and fork,” including wastes in processing, transportation, and storage (waste management is discussed in chapter 6, Cordell et al. 2009).

Different people contribute to, and are affected differently by, P-use and P cycling. For example, the role of P in limiting crop production or in impairing water supplies differs considerably across the globe (chapter 8). In sub-Saharan Africa and in most countries with highly weathered soils, P is the limiting nutrient for plant growth. Agricultural production in these regions requires increases in P fertilizer application to maintain high yields for increasing human populations (Drechsel et al. 2004, Van Wambeke et al. 2004). At the same time, in many parts of the United States and Europe, P has been over-applied for many years, leading to high

concentrations of P in agricultural soils and runoff, and consequent freshwater eutrophication (Bennett et al. 2001; Carpenter et al. 1998, see chapters 4 and 5 for more discussion). While the benefits of changing patterns of P-use to reduce downstream pollution may be more important to more developed countries, the effect of P-use on the price and availability of P may be more important to less developed countries.

Economy

Globally, most economically viable mineral P resources are controlled by only a few countries. This makes current and future P availability and accessibility very uncertain. Geopolitical tensions may affect the availability of P resources around the world and these tensions will only increase as supply declines and demand increases, causing prices to increase—perhaps dramatically (chapter 3). The problem of P supply is thus less one of geologic scarcity than of economic or geopolitical scarcity. Regions vary both in access to P and access to capital, labor, and technology to deal with P scarcity and eutrophication (chapter 8). For example, the current fraction of total farm operating costs that fertilizer purchases represent dramatically alters the effect of P price fluctuations on food systems and the response farmers and consumers have to such price fluctuations. Compared with Europe, P fertilizer is more expensive in sub-Saharan Africa—both in real price and as a proportion of a farm's budget—where sub-Saharan farmers have relatively less purchasing power. This means that **P accessibility*** for a sub-Saharan African farmer is considerably lower than for a European farmer, even though both are using mineral P from the same source (Cordell et al. 2009). Because of this disparity, traditional market forces (e.g., fertilizer prices) may not begin to enforce P conservation in richer countries until long after there is considerable food scarcity in the developing world. The lessons of the 2008 food crisis demonstrate that political instability often accompanies such adversity.

In summary, global P dynamics are a result of complex interactions of environmental, social, and economic factors operating at many scales. The diversity of local needs and the capacity to deal with P scarcity or P pollution challenges highlight the need for a sustainability approach that does not use “one-size-fits-all” solutions. However, before looking to the future, it is important to understand how the problematic P cycling we have identified came to be. Such a historical perspective is essential to understand what has influenced us to utilize P in the way we have and subsequently identify key aspects of resource, farm, and food management that need to be altered in moving forward (chapter 9).

HOW WE GOT TO THE CURRENT STATE OF P-USE

Early farming relied on P already in soils, on natural P inputs (such as sedimentation associated with flooding and chemical weathering of parent material), and on tight and efficient recycling of P (Ashley et al. 2011). In this early human P-cycle, P cycled much more conservatively relative to modern agro-ecosystems. Low-impact (i.e., less irreversible or large-scale changes in ecosystems in and around agricultural areas) food production was largely sustainable for thousands of years, with little need for outside nutrient additions, and had limited long-term downstream effects (Filippelli et al. 2008). The levels of P in any soil are highly localized and dependent on climate, topography, rates of **pedogenesis***, ecosystem age, and bedrock characteristics. As such, early societies developed methods of agriculture that worked with their local climates and soil types. However, such systems were far from perfect, as famines were more frequent and agriculture was mostly subsistent or limited in economic scope (Ashley et al. 2011). As P levels declined in soils (via leaching, occlusion, or crop uptake), communities dependent on these soils would either employ measures such as burning their fields to unlock bound P (Cordell 2001), wait for spring floods to renew their soil (e.g., annual silt deposits along the Nile River), or, in some cases, farmers were forced to find more fertile fields in other locations.

As human populations grew (and became more sedentary), soil amendments became necessary to maintain soil fertility (Ashley et al. 2011). The use of human and animal excreta (particularly from herbivores) on fields has long been practiced, particularly in China (Liu et al. 2008). Middle Eastern desert dwellers maintained collections of pigeons not only for their meat but, perhaps more importantly, for their P-rich guano, which was applied to soils that supported fruit trees and small gardens (Tepper 2007). These are just a few examples of locally sourced applications of P amendments in early agriculture. As reflected throughout this book, these systems of P application gave way in modern times to linear rather than circular modes of crop fertilization, food consumption, and waste management due to increasing demands for inexpensive food.

Starting in roughly the nineteenth century, global use of P switched from an **open cycle*** to a **closed cycle**.* Localized P sources were now sourced from locales that were much more distant from their intended destination (Figure 1.3), especially in Westernized agriculture. With urbanization, food consumption and waste production increasingly took place at some distance from crop production. Excreta were no longer systematically returned to farm fields due to the advent of modern sanitation practices (chapter 7). Furthermore, animal and feed production also became separated, as agricultural systems industrialized and farms specialized, leading to reduced on-field manure recycling. Countries such as England and the United States, in

FIGURE 1.3 Changes in phosphorus inputs from 1800 to 2010. Black arrows represent flows of P from one pool to another. Gray arrows represent a return of P to a previous pool. The source of P inputs to agricultural fields has changed considerably from a largely localized, organic source (e.g., night soil, animal manures, crop residues) to a source largely dominated by inorganic sources such as mineral P. Figure created from concepts put forth in Ashley et al. 2011.

order to create organic liquid fertilizers, imported P as animal bones treated with sulfuric acid (Ashley et al. 2011). In the mid-1800s, bat and sea bird guano was mined and imported from South America and islands in the South Pacific (Ashley et al. 2011). As these sources were quickly exhausted and became increasingly expensive to process and transport, mineral P from mining soon became the fertilizer of choice for modern agriculture, due to its higher concentration of P available for crop use relative to organically sourced P like manures (Figure 1.4). Agricultural demand during the last 75 years—a result of the **Green Revolution***—increased global P mobilization by roughly fourfold (Filippelli 2008). During this time human population doubled and the consumption of meat and dairy foods increased (Falkowski et al. 2000, Villalba et al. 2008). Through this revolution, the nature of agricultural operations changed toward large, commercial monoculture production (which we refer to as the “agro-industrial complex”) in response to increasing demand for food, fiber, and meat products (although small-scale farming still persists, especially in developing countries). The separation of P supply and demand, which characterized the development of this agro-industrial complex, was largely made possible by the use of cheap fossil fuels that characterized the twentieth century, making

FIGURE 1.4 Phosphorus use and dependency has changed considerably since humans began practicing wide-scale agriculture. Over time, P inputs to field have become far less localized and sourced from increasingly inorganic sources (e.g., mineral forms). Figure created from concepts put forth in Ashley et al. 2011.

large-scale mining, manufacture, and transportation of P fertilizer an economically viable option. As soon as large-volume international trade and growing populations became part of the human P cycle, human P-use became less cyclical and increasingly unsustainable.

Human demand for P is only expected to grow (Childers et al. 2011). If the human population grows by two to three billion people by 2050, and if that larger population is more affluent (Childers et al. 2011), global food production will have to increase by 70 percent to 100 percent (not including added agricultural demand from biofuels production; see chapter 4). In a future in which mineral P resources may become more scarce and expensive, the implications of this dramatic increase in demand are significant for global food security and international relations (chapter 8). Intergenerational equity will also be a growing concern if we continue to manage P resources as we have in the recent past. Clearly a new, more sustainable approach is needed.

HOW A SUSTAINABILITY “LENS” SHAPES SOLUTIONS TO P MANAGEMENT

Sustainability is not simply about using resources more efficiently. In fact, efficiency in food production, including the use of P, has increased through the Green Revolution (Baker et al. 2011), but food security and P sustainability continue to be problems. Thus, although more efficient use of resources may be part of a sustainable solution, a more holistic, or systems, perspective that considers the complex

relationships among resources and people is essential. Sustainability focuses on social equity and standard of living, and our relationship to the environment is key because it supports all human activities. Sustainability is not about maintaining the status quo (i.e., sustaining what we currently have). There are plenty of undesirable system-states that are resilient to change (e.g., the “poverty trap”). To the contrary, sustainable solutions seek to improve the current state of a system by accepting our dependence on the environment as our life support system while at the same time including humans and social equity as a fundamental part of the solution. Sustainability is a process, not an endpoint, and most sustainability plans are action-oriented, iterative processes (Figure 1.1, explored in more detail in chapter 9). Effective sustainable solutions require nimble and reflexive responses to changes in the situation. Finally, sustainability science focuses on understanding the trade-offs that inevitably occur when we make various decisions or implement various interventions.

THE TIMING OF P SUSTAINABILITY

Phosphorus resource management is a global sustainability challenge to which there are many possible solutions. Everyone, from households to nations, has a stake in food security, clean water, and geopolitical stability. There is no biological substitute for P, but there are substitutes for the inefficient ways in how we currently use P. Unlike energy, which can only be transformed, P can be recycled. In nature, the P cycle is one of the most conservative of the major macronutrients (Chapin et al. 2002). Thus, instead of materials substitution, we may use “process substitution” with P. This is when we replace inefficient processes that cause P to be lost from the human P cycle with processes that recycle P back into food production. If we were to replace the [largely] linear path of P through our food system with a more cyclical one (Childers et al. 2011), we could dramatically reduce the need for mineral P resources. This “de-linearization” of the P cycle will require a **transdisciplinary*** approach (chapter 9) in which multiple disciplines of science work together and which includes policy makers and practitioners that affect or are affected by a problem (we address the identification of stakeholders in chapter 9). This trans-disciplinary approach allows for a more complete understanding of the problem. In addition, by having multiple interests and perspectives at the table, there is a better chance that negative trade-offs between proposed solutions may be avoided. Perhaps most importantly, this broad approach to identification of challenges and the development of solutions is preferable to having a small group of stakeholders decide what should or should not be done. In other words, holistic approaches are based on “buy-in” by all involved. Together, people can create visions of desirable futures and partake in their realization.

SYSTEMS VS. LINEAR THINKING

A “systems-thinking” approach to sustainability involves solutions that coordinate efforts in multiple sectors of a problem. Truly sustainable solutions to P-use will almost certainly include transformational change rather than a mere collection of small corrections, or “tweaks,” to our current system. In the case of P, this means that simply considering solutions for discrete steps in the human P cycle will be insufficient. The use of more P-efficient crop varieties by farmers would be an important “tweak” to the existing agro-industrial complex, while a large-scale rethinking of when, where, and how crops are grown would be a transformational change. For example, perhaps some food must be produced closer to cities, where urban waste (a “source” of P) can be more easily reincorporated into food production. Perhaps polyculture and the reintroduction of small-scale animal husbandry on crop farms would be appropriate to both minimize P losses to waterways while decreasing the amount of P the farm must import. Importantly, holistic approaches should avoid large trade-offs with other essential resources or services. For example, solutions to the P-use issue that substantially increase energy use (especially from fossil fuels) would in most cases be unsatisfactory.

Another important component of the sustainability “lens” is the development of an iterative and reflexive process that regularly assesses how the system is changing in response to interventions and adjusts solutions appropriately (Figure 1.1b). Increased understanding of the current state better informs interventions, but this is not enough to ensure that long-term goals are met. As we intervene to change a system, we change the nature of that system and must be willing to constantly reassess the path forward. The need for such an iterative structure highlights the need for involvement by policy makers, practitioners, and citizens—as they will be able to report what works and what does not work—and they must be part of a nimble, flexible governance structure (by proposing, voting, and participating; chapter 9).

A wide range of technological, behavioral, and political solutions are available to improve reuse and recovery of P resources (as well as efficiency of P resource use), and all of them will likely contribute to achieving P sustainability and thus food security (Cordell et al. 2011). Although P sustainability is a global challenge, vulnerability to P scarcity and to P eutrophication varies considerably around the globe and tends to be manifest much more locally (chapter 2 for biophysical reasons, chapter 4 for case study examples, chapter 7 for cultural norms, chapter 8 for international aspects). Similarly, solutions often need to be tailored to regional, even local, characteristics. For example, one clear goal should be to decrease per capita consumption by, and

Thus, the sustainability “lens” is a way to examine systems, identify problems, and come up with long-range solutions. The global P-use issue is a “wicked problem” that can benefit from such a sustainability “lens.” This book uses this lens to further characterize the challenges we face with current patterns of human interactions with P and to explore strategies to move toward a more sustainable system (Figure 1.5).

FIGURE 1.5 (A) Each chapter in the book encompasses all three spheres of sustainability. (B) With the human P cycle as a backdrop (modified from Childers et al. 2011), we show the aspects of the cycle that are covered in each of the book chapters. Note that there is considerable overlap among many of the chapters (e.g., 4, 5, 6 and 7) and that chapters 1, 2, 8, and 9 address the entire human P cycle.

BOX 1.2

CHAPTER 1 SUMMARY

- Over the course of human history, the human P cycle has changed from a more closed system (recycled and recovered P) to a very open one (P loss) that degrades ecosystem services.
- P management is a sustainability problem because issues regarding P are integrated and embedded within the three spheres of sustainability (environment, society, and economy).
- The problem of P sustainability is global, but solutions must be locally appropriate and must consider both time and place.
- The sustainability lens influences what solutions should be considered in P management by taking a systems perspective rather than a more conventional, linear approach.
- A sustainability perspective accounts for and integrates environmental, social, and economic influences in a particular time and place. This perspective often involves transdisciplinary engagement in an iterative, problem-solving process working toward a vision of a sustainable future.

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