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Food Fight

Moving beyond Wizards vs Prophets to Achieve a Sustainable Phosphorus System

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In 1970 Norman Borlaug was awarded the Nobel Peace Prize 'for having given a well-founded hope – the green revolution'. Borlaug's contribution – his development (through selective breeding) and relentless deployment of high-yield varieties of wheat – was one of the key pillars of the Green Revolution, in which global food production tripled with only a 30 per cent increase in farmland area (Pingali 2012). A recent book (*The Wizard and the Prophet* by Charles Mann) posits Borlaug as a central figure of the twentieth century, an exemplar of techno-centric optimism that would use scientific insights and engineering applications to solve humanity's challenges, including its rapidly expanding population in such effective ways that they seem magical even (Mann 2018). Borlaug was a Wizard. Borlaug's legacy in the world of agriculture persists, manifested in the wizardly promise of genetically engineered crops (the 'Gene Revolution'), precision agriculture, and artificial intelligence on the farm.

Interestingly, less appreciated components of Green Revolution wizardry have impacts on water: increased reliance on irrigation that allowed expansion of cropping into dry regions and increased application of chemical inputs, including pesticides and fertilizers that often move from farms into streams, rivers, lakes, and oceans. While the secondary and broadly diffused impacts of these inputs came to widespread awareness via the impacts of DDT illuminated by Rachel Carson, the impacts of agricultural fertilizer use also became collateral damage of Green Revolution wizardry, seemingly inevitable given the low nutrient content of many soils and the fact that continuous removal of crops leads to depletion of soil nutrients. In Mann's book, alarm about the expanding impacts of agricultural intensification was manifested in the persona of William Vogt. The 'Prophet' of Mann's dialectic, Vogt was an ecologist and conservationist and later became the National Director of Planned Parenthood. Throughout his life he spoke of the dangers of exponential population growth, resource depletion, and environmental degradation that would lead to collapse of civilization. In *The Wizard and the*

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Prophet, Mann proposes that the tension between Borlaug and Vogt and their respective proponents manifested itself throughout the twentieth century in competing worldviews in which human material progress is confronted by environmental apocalypse.

Indeed, we can now see Vogt's alarm calls echoing in the concept of 'planetary boundaries', a situation that is not surprising given the massive impacts of modern agriculture on all dimensions of the Earth system. Consider the planetary boundaries for phosphorus. In the first application of planetary boundaries for the major biogeochemical nutrient cycles (nitrogen, phosphorus) (Rockström et al. 2009), human perturbation of nitrogen cycle (largely via the Haber–Bosch reaction for fertilizer production) was recognized to be well beyond sustainable levels due to its impacts on climate change (via the greenhouse gas, N_2O) and its role in stimulating algal blooms in N-limited coastal oceans. It was recommended that N use should be brought to levels somewhat arbitrarily set at 25 per cent of then-current (2009) fluxes. However, Rockström et al. (2009) stated that phosphorus cycling was currently within safe operating limits for humanity but that an 11-fold increase in P fluxes beyond pre-industrial background levels would lead to increased risk of large-scale ocean anoxia. This proposition was somewhat surprising to freshwater scientists as it seemed to ignore P's primary role in driving eutrophication of inland waters, central to drinking water supplies, fisheries, and aquatic biodiversity. In response, Carpenter and Bennett (2011) estimated planetary boundaries for P impacts on freshwaters and concluded that fluxes had already exceeded levels that would induce widespread eutrophication of inland waters. Accordingly, updated assessments of planetary boundaries acknowledge that both the N and the P cycles exceed safe operating levels (Steffen et al. 2015; see also Figure 1.1 in this book's introductory chapter). Indeed, nutrient emissions (N, P) constitute two of the three key control variables that currently fall in the 'high risk' category, well beyond their safe operating limits.

Other voices in the mould of Mann's Vogtian Prophet continue to sound the alarm about humanity's unsustainable phosphorus path (Brownlie et al. 2022; Elser & Bennett 2011) and have even raised concerns not only about the impact of phosphorus on water quality but also about possible looming shortages of phosphate rock for fertilizer production (Cordell et al. 2009; Elser 2012). While those concerns have been dampened by upward revision of estimates of phosphate rock availability (Van Kauwenbergh 2010; but see Edixhoven et al. 2014), the price of phosphate rock nevertheless has undergone unprecedented recent volatility (Elser et al. 2014) and has increased at nearly twice the rate of inflation since 2003, including a very large price spike of more than 700 per cent in just a few months in 2007. Furthermore, the 2010 upward revision of phosphate rock reserve estimates by Van Kauwenbergh (2010) was entirely due to recognition of geological

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deposits found in Morocco, which now controls more than 70 per cent of known phosphate rock reserves (Garside 2022), placing it in an unusually powerful position with respect to current and future supplies of this essential farm input.

So, whither the Wizard and Prophet in the world of phosphorus? In Mann's telling, this conflict is one between techno-optimists in the world of agriculture and pessimistic doomsayers in the world of environmental science, locked in enduring battle in a polarized political arena (Oury 2019). But is this the case? With respect to phosphorus, I would propose that the dichotomy is not so easily crystallized in this framework. First, the players in conflict both have what seem to be universally embraceable values (it is good to protect others from suffering) and unassailable goals (Who is against 'feeding the world'? Who opposes clean water?). Second, techno-optimists also abound on the water protection side of the coin not just on the agricultural production side. Third, Mann's view of this enduring dichotomy does not recognize emerging efforts to move beyond it to achieve more holistic and systems-level approaches to the challenge of planetary P sustainability. Indeed, the situation described by Mann is reminiscent of a classic critique of 'command and control' in natural resource management (Holling & Meffe 1996) in which increasingly intensive and heavily capitalized interventions are imposed in order to reduce or eliminate undesirable environmental variations, reducing ecological complexity and compromising resilience. Next I discuss these difficulties with Mann's dichotomy.

Those promoting increased agricultural production to 'feed the world' may indeed consider themselves on high ethical ground, but such a position becomes more assailable when considering the agricultural system as it currently operates. Most notably, only ~60 per cent of agricultural production goes into growing food that is directly consumed by humans (mostly as grains such as rice and wheat) while 35 per cent goes to growing feed for animals (Elser & Haygarth 2022). While meat and dairy do carry considerable nutritional value, it is hard to argue against the view that 'feeding the world' would be a lot easier if diets contained less meat and relied more on plant-derived fats and proteins. Ethical dimensions connected to animal welfare are also prominent here. Non-food crop commodities make up the final share of agricultural production that does not 'feed the world', and these include biofuel crops that, arguably at least, are being produced in order to bring humanity within safe operating limits for climate change. Indeed, production of ethanol increased threefold and biodiesel increased fourfold between 2000 and 2021 (Elser & Haygarth 2021). A notable example of this is cultivation of corn for ethanol production in the USA, which constituted 32 per cent of corn production and 10 per cent of fertilizer use in the USA in 2009. Expansion of the Renewable Fuel Standard (RFS) in 2007 further increased fertilizer use by 3–8 per cent (Lark et al. 2022). The benefits of this effort for staying within the climate

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change safe operating space remain unclear. While early analyses indicated that corn-derived ethanol had lower carbon intensity than gasoline thus allowing it to fall within the RFS programme (Lark et al. 2022), a more recent analysis that takes into account the emission effects of expanding corn cultivation and altering land use indicates that the carbon intensity of corn ethanol is no better than gasoline and is likely 24 per cent higher (Lark et al. 2022). While this report has drawn criticism (though not yet in the peer-reviewed literature), given the well-known and intense local impacts of fertilizer runoff on water quality in corn-intensive regions as well as the downstream impacts of exported nutrient pollution on coastal waters (e.g. the Gulf of Mexico 'dead zone'), continued promotion of ethanol production on croplands that are suitable for cultivation of food for human consumption seems ethically dubious given that beneficial impacts on carbon emissions are probably minimal. Current practices are likely a reflection of strong political forces at play in sustaining programmes like the Renewable Fuel Standard.

Are the Prophets who challenge agricultural Wizards in defence of the environment blameless in these contests? It might seem so since, after all, clean water is essential for human well-being, and non-point source pollution from agriculture is a dominant cause of water pollution in many regions, including the USA (Stets et al. 2020), Europe (Werner & O'Doherty 2012), and China (Liu et al. 2016; Zhang et al. 2022). However, once again the ethical scene is murkier than one might imagine. The main complicating factor, of course, is the imperative discussed earlier – to feed the world. While global hunger has been gradually diminishing (but worsened during the COVID-19 pandemic), 10 per cent of the world's population still suffer from hunger while nearly one-third don't have regular access to sufficient food (United Nations Department of Economic and Social Affairs 2022a). In addition, world population just passed 8 billion and is estimated to reach 9.7 billion by 2050 (United Nations Department of Economic and Social Affairs 2022b). It is difficult to imagine how this population can be fed without extensive fertilizer use, even if progress is made in restructuring diets and targeting fertilizer use to food crops. Furthermore, substantial reductions in fertilizer use would, eventually at least, reduce crop yields per unit of farmed land. In this scenario, increased food production can only take place by further conversion of forest, grassland, and desert ecosystems into croplands, accelerating biodiversity loss (a planetary boundary humanity has already exceeded). So, we are faced with an ethical conundrum: thirst cannot trump hunger but neither can hunger trump thirst.

And what of Mann's assignment of techno-optimists exclusively to the Borlaugian agricultural camp? Are agriculturalists the only ones who think we can invent our way out of the phosphorus dilemma? Looking at the range of responses being mustered to meet the challenge of phosphorus pollution, the answer is

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clearly 'no'. Many new technological approaches are now in early deployment or active development to meet the phosphorus sustainability challenge on the 'downstream' side of the problem. (Note that various pieces of wizardry are being deployed or developed for agricultural practices to address P sustainability, from genetic engineering to improve crop fertilizer use to precision agriculture to complex soil amendments and microbiome adjustments to cellular agriculture.) Technologies to intercept lost phosphorus from various forms of 'waste' and return it for re-use include struvite precipitation equipment that recaptures P in wastewater treatment plants, anaerobic bioreactors that use animal manure to produce biogas and concentrated nutrient solutions, and urine source separation. So, from among the Prophets also arise Wizards, both, it seems, seeking to apply a range of technological fixes to a complex food–water system that encompasses both natural and anthropogenic ecosystems that are globally linked via trade and environmental flows.

How then can the phosphorus sustainability challenge be met in a fair and ethical manner? I would follow in the spirit of Holling and Meffe (1996) to argue that, while both Prophets ('problem finders') and Wizards ('problem fixers') will always be needed, both on the food side and on the water side of the food–water nexus, we need to move rapidly towards new ways of thinking and doing that embrace the full range of system complexity involved. Einstein apocryphally said, 'The definition of insanity is doing the same thing over and over again and expecting different results.' In the same vein, Einstein or Ram Dass or Marc Prensky or maybe someone else said: 'The problems that exist in the world today cannot be solved by the level of thinking that created them.' We need new ways of thinking about food systems and about water systems and about how both are wrapped into a complex web that connects biogeochemistry, hydrology, nutrition, politics, and culture. In our book *Phosphorus: Past and Future* (Elser & Haygarth 2022), Phil Haygarth and I call for the emergence of a new kind of thinker who we call a 'Systems Innovator', someone who has the systems perspective of a Prophet combined with a Wizard's drive to innovate. Systems Innovators possess not only deep technical expertise but also the 'soft' human skills to communicate knowledge and to navigate the complex ethical, political, and cultural terrains within which P sustainability must emerge. Haygarth and I see Systems Innovators primarily as individuals who provide leadership and serve as 'boundary persona' (akin to 'boundary objects,' sensu Star & Griesemer (1989)) to provide trusted connections between disparate sectors and stakeholders (e.g. grower associations and water resource managers) that need to cooperate to transition towards more sustainable practices. For example, Systems Innovators would recognize that current livestock production is ethically problematic and is a major driver of nutrient pollution and of heavy P fertilizer use (a la Vogt) and that radical

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technological innovations (a la Borlaug) such as cellular agriculture ('stem cell meat') are likely to emerge from food science Wizards. However, they would also recognize, analyse, and work to minimize concomitant environmental impacts of cellular agriculture, they would acknowledge the potential for strong cultural and psychological barriers to this novel technology, and they would provide strategies by which informed community engagement could shape the political environment within which necessary markets and regulations involving cellular agriculture would emerge. Additionally, 'Systems Innovation Alliances' might emerge as 'boundary organizations' that serve the same function, independent of the particular individuals who populate them. In the domain of the phosphorus challenge, examples might be the European Sustainable Phosphorus Platform (ESPP), which was

> formed in March 2013 through a declaration, signed by over 150 organisations after the first European Sustainable Phosphorus Conference. ESPP ensures knowledge sharing, experience transfer and networking for opportunities in the field of phosphorus management, facilitates discussion between the market, stakeholders and regulators, addresses regulatory obstacles, contributes to policy proposals, circulates information by newsletters, website, conferences and publications, promotes Platform Members' activities, and contributes to define a long-term vision for phosphorus sustainability in Europe. (European Sustainable Phosphorus Platform 2022)

Another example is the Sustainable Phosphorus Alliance (SPA), whose website states that it is

> a member organization addressing the complex problem of phosphorus sustainability. We are North America's central forum and advocate for the sustainable use, recovery, and recycling of phosphorus in the food system. We collaborate with our members and supporters to innovate and implement evidence-based solutions to the phosphorus sustainability challenge, to be shared and accessible to the community. (Sustainable Phosphorus Alliance 2022)

SPA's membership consists of mining companies, water suppliers and agencies, waste treatment companies, and academic research programmes. (Full disclosure: I am the director of SPA, but its mission and activities would, I can hope, persist in my absence.)

The Wizard and the Prophet is a vision of prevailing attitudes of the twentieth century. In the twenty-first century we confront the now-obvious consequences of the insufficiency of the actions and inactions that emerged from past tension between these two poles. This is seen in ongoing climate change, large-scale deforestation and other habitat destruction, and widespread diffuse agricultural pollution that are the red flags of the now-emblematic planetary boundaries, the flashing lights on the dashboard of planetary life support systems about to fail. In the example of phosphorus, we see an imperative to create new ways of being, thinking, and acting to reconcile justifiable moral actions of one group ('Feed the world!') with justifiable moral outrage of others ('Save our drinking water!', 'Save

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our fish!') in order to return to safe operating conditions. In the coming decades we will see if Systems Innovators, or some similar operators or institutions, emerge in sufficient numbers and with sufficient influence to harmonize these conflicting voices to bring about a sustainable food–water system, one in which nutritious food is abundantly available to all and in which lakes, rivers, and oceans thrive once again.

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