What is our point of no return? Caesar proclaimed ‘the die is cast’ while crossing the Rubicon, but rarely does modern society find so visible a threshold in our continued degradation of ecosystems and the services they provide. Humans have always used their surroundings to make a living—sometimes successfully, sometimes not (Diamond 2005)—and we intuitively know that there are boundaries to our exploitation. But defining these boundaries has been a challenge since Malthus first prophesied that nature would limit the human population (Malthus 1798).

In 2009, Rockström and colleagues tried to quantify what the 6.8 billion (and counting) of us could continue to get away with, and what we couldn’t (Rockström et al 2009). In selecting ten ‘planetary boundaries’, the authors contend that a sustainable human enterprise requires treating a number of environmental thresholds as points of no return. They suggest we breach these Rubicons at our own peril, and that we’ve already crossed three: biodiversity loss, atmospheric CO₂, and disruption of the global nitrogen (N) cycle. As they clearly hoped, the very act of setting targets has provoked scientific inquiry about their accuracy, and about the value of hard targets in the first place (Schlesinger 2009). Such debate is a good thing. Despite recent emphasis on the science of human–ecosystem interactions, understanding of our planetary boundaries is still in its infancy, and controversy can speed scientific progress (Engelhardt and Caplan 1987).

A few weeks ago in this journal, Carpenter and Bennett (2011) took aim at one of the more controversial boundaries in the Rockström analysis: that for human alteration of the global phosphorus (P) cycle. Rockström’s group chose riverine P export as the key indicator, suggesting that humans should not exceed a value that could trigger widespread marine anoxic events—and asserting that we have not yet crossed this threshold. There are defensible reasons for a marine-centric boundary (Filippelli 2008, Handoh and Lenton 2003). However, human alteration of the P cycle has multiple potential boundaries (figure 1), including P-driven freshwater eutrophication (Smith and Schindler 2009), the potential for world P supply to place an ultimate limit on food production (Smil 2000, Childers et al 2011), and depletion of soil P stocks in some world regions (MacDonald et al 2011).

Carpenter and Bennett revisit the P boundary from the freshwater eutrophication perspective. Given the extraordinary variation in freshwater ecosystems across the globe, this is a challenging task, but the authors strengthen their analysis by using three different boundaries with relevance to eutrophication, along with two water quality targets and a range of estimates of P flow to the sea. In doing so, they make a compelling case that if freshwater eutrophication is indeed a Rubicon, we have already crossed it.

Importantly, Carpenter and Bennett go beyond the calculation of new boundaries to make broader points about humanity’s relationship with the P cycle. Disruptions of both the P and N cycles are mostly about our need for food (Galloway et al 2008, Cordell et al 2009), but unlike N, P supplies are finite and irreplaceable. Environmental concerns aside, we can fix all the N₂ from the atmosphere we want—but deplete our economically viable P reserves and we’re in trouble.
Figure 1. Human alteration of the global P cycle has multiple possible boundaries. These include the environmental risks posed by freshwater eutrophication and marine anoxic events, and the food security risks that come from depletion of soil P stocks in some world regions, as well as finite global supplies of high-value mineral P reserves. Photo credits beyond authors: upper left, Shelby Riskin; upper right, Pedro Sanchez.

In effect, Carpenter and Bennett argue that among P’s multiple boundaries, the one for freshwaters is less forgiving of our current activities (but no less important) than is the one for oceans. Encouragingly, while they argue that we’ve already crossed one key boundary in the P cycle, they also suggest it’s not a Rubicon moment. The inefficiencies in P use that motivate these boundary debates are also clear targets for improvement, and some world regions may be on a trajectory towards greater P use efficiency (Vitousek et al 2009). This is a critical step for society, because even absent concerns over freshwater eutrophication or marine anoxic events, accelerating rates of P mining and inefficiencies in agricultural P use would still pose very real threats. There is legitimate debate over when readily accessible P reserves may run out (Cordell et al 2009, Van Kauenbergh 2010), but nobody argues with their finite nature. Sooner or later, we will be forced to keep P out of our waterways, if only because we will have to keep it on our farms.

Without such a shift, we may face severe P constraints to food security within just a few human generations. As current P reserves decline, rising economic values of low concentration P stores may catalyze their harvest, but without considerable policy interventions, that price hike would exacerbate already strong global inequities in the distribution and use of chemical fertilizers (Sanchez and Swaminathan 2005). The harvest of low concentration P reserves would also create substantial collateral damage to the surrounding environment.
Furthermore, even without exhaustion of high-concentration P reserves, their location in only a few countries creates geopolitical risks from the demand for an increasingly valuable resource (Cordell et al 2009).

Policies aimed at lowering P inputs to aquatic environments will not only reduce the eutrophication risks explored by Carpenter and Bennett, they will increase P retention in agricultural landscapes and slow the decline of finite P reserves. Shifts in human diets can also make a profound difference in the amount of P (and N) required to meet caloric needs. Society can (and ultimately must) learn to capture and re-use P in human and animal wastes. And, as Carpenter and Bennett highlight, inequities in P availability across world regions are not just a problem, they are an opportunity: transfers from P-rich to P-poor regions could simultaneously reduce environmental and food security risks.

Above all, Carpenter and Bennett's analyses highlight the need for new management strategies that better target not only P's environmental risks, but also recognize the element’s standing as an irreplaceable resource. Human society has been built from the massive alteration of four global biogeochemical cycles (C, N, H2O and P). We can replace carbon-based fuels, plant legumes in lieu of Haber–Bosch-based N fixation, and the rain will still fall. But for P, there is neither substitute nor renewal. Without an almost closed loop between fertilizer application, food consumption, and waste management, society could solve the remainder of the environmental threats Rockström and colleagues identify, and still be facing a bleak future.

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