

The End of the Road? Agricultural Revolutions in the Capitalist World-Ecology, 1450–2010

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Does the present socio-ecological impasse – captured in popular discussions of the ‘end’ of cheap food and cheap oil – represent the latest in a long history of limits and crises that have been transcended by capital, or have we arrived at an epochal turning point in the relation of capital, capitalism and agricultural revolution? For the better part of six centuries, the relation between world capitalism and agriculture has been a remarkable one. Every great wave of capitalist development has been paved with ‘cheap’ food. Beginning in the long sixteenth century, capitalist agencies pioneered successive agricultural revolutions, yielding a series of extraordinary expansions of the food surplus. This paper engages the crisis of neoliberalism today, and asks: Is another agricultural revolution, comparable to those we have known in the history of capitalism, possible? Does the present conjuncture represent a developmental crisis of capitalism that can be resolved by establishing new agro-ecological conditions for another long wave of accumulation, or are we now witnessing an epochal crisis of capitalism? These divergent possibilities are explored from a perspective that views capitalism as ‘world-ecology’, joining together the accumulation of capital and the production of nature in dialectical unity.

Keywords: capitalism as world-ecology, agricultural revolution, agrarian question, environmental history, political ecology

A THEORETICAL FRAMEWORK

I begin with two questions. First, if neoliberalism is in crisis, what kind of crisis is it? Second, how does a production of nature perspective reshape our understanding of neoliberalism, and of previous crises in historical capitalism?

‘Neoliberalism’ is a mighty signifier, and one mobilized to describe all manner of socio-ecological movements in every region and at every scale since the early 1970s. The era as a whole is a messy bundle of contradictions that defies neat and

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tidy definition. Not least, the neoclassical ideological project provides little guide to actually existing capitalism as a whole, in the years following the initial crisis of the 'golden age' postwar world-economy and the Pax Americana (c. 1971–4). Highlights of this neoliberal era would surely include the following. By 1979, the United States had embarked upon a significant program of military Keynesianism, subsequently accelerated and codified by Reagan's election (Harvey 2005). The era's greatest economic 'miracle' – the rise of China – has been supervised by a *dirigiste* state of the first order (Li 2008). The leading economic powers, grouped in the OECD, saw government spending rise from about 25 per cent of GDP in 1965 to more than 37 per cent three decades later (Cooper 2001, 195). And not least, global trade liberalization, especially that centred on the World Trade Organization and its Agreement on Agriculture, has seen no withdrawal of the state on a systemwide basis. As Tony Weis has shown (2007), the leading states of the global North (the USA above all) have not wavered for a moment in their support of domestic agro-food sectors while pursuing the radical liberalization of peripheral economies. It is for good reason that Gee characterizes the neoliberal era as one of 'structural mercantilism' (2009).

My concern is with neoliberalism as a phase of world capitalist history, and therefore a specific moment in the modern world-system's patterns of evolution and recurrence. I highlight two, dialectically bound, phenomena that constitute *part* of the *differentia specifica* of the neoliberal era. First, I regard neoliberalism as a distinctive phase of capitalism premised on *taking* first, and *making* second. This is the 'Robin Hood in reverse' character of neoliberalism – stealing from the poor and giving to the rich – illuminated by Harvey (2005), Duménil and Lévy (2004) and many others. Neoliberalism, like all previous phases of capitalism, has redistributed wealth; *unlike* all previous phases of capitalism, it has not generated the conditions for renewed economic growth and a broadly defined social development. As Balakrishnan noted recently (2009), neoliberalism has failed to generate that 'third technological revolution' upon which so much attention was lavished in the 1970s (Mandel 1975). Technological development has certainly occurred – above all, in control and information technologies – but at all turns it has 'failed to release a productivity revolution that would reduce costs and free up income for an all-round expansion' (Balakrishnan 2009, 14). Nowhere is this more evident than in agriculture, where nearly three decades of experimentation with genetically modified organisms has succeeded in transferring wealth and power from farmers to big capital without any success in raising intrinsic yields (Gurian-Sherman 2009).¹

The second distinctive feature of capitalism in the neoliberal era concerns the penetration of finance into everyday life, and above all, into the reproduction of extra-human nature. This is at the core of the 'transition from the formal to the real subsumption of nature to capital' since the 1970s (Boyd et al. 2001). Financialization, of course, is not new, and its cyclical resurgence has been with us since the sixteenth century (Arrighi 1994). The term 'financialization' itself is subject to

¹ We may 'distinguish between two kinds of yield – intrinsic yield and operational yield – when evaluating transgenic crops. Intrinsic yield, the highest that can be achieved, is obtained when crops are grown under ideal conditions; it may also be thought of as potential yield. By contrast, operational yield is obtained under field conditions, when environmental factors such as pests and stress result in yields that are considerably less than ideal' (Gurian-Sherman 2009, 2).

multiple readings, so we can take care to emphasize financialization as a gravitational field that influences and shapes the rules of reproduction for human and extra-human nature – working-class households come to depend on credit cards to pay medical bills, and forest, field and mine become disciplined by a rate of profit established not in industry, but in finance – that is, disciplined by a circuit of capital that runs M–M+ not M–C–M+:

What this means in practice is that the real economy of goods and services has been subordinated to the competitive logic of global financial markets. Food companies, for example, are no longer simply competing in yoghurt, or carbonated drinks or processed meats. They are competing on financial markets to deliver the fastest and biggest possible rates of return to ‘impatient’ financial capital. (Rossman 2007, 5)

Taken together, these two movements specific to neoliberalism – although certainly known in earlier phases of capitalism – generated a development model premised on one part redistribution, one part ‘bubble economy’. The era since the 1997 Asian-centred financial crises may be regarded as a long series of bubbles. Indeed, the stabilization of world markets at the time of writing (January 2010), made possible by the injection of no less than \$15 trillion into the world financial system by the OECD governments in 2008–9 (Mason 2009), may properly be regarded as a ‘bubble recovery’. I take as my guiding thread the hypothesis that neoliberalism has reached the limits of developmental possibilities, the financial crises and inflationary crescendo of 2008 marking the ‘signal’ crisis of the neoliberal ordering of relations between humans and the rest of nature. Adapting Arrighi’s useful language (1994), we can say that a *signal crisis* of an ecological regime occurs when the initial conditions for a rapid expansion of the ecological surplus begin to erode and food, energy and inputs become more, rather than less, expensive. A *terminal crisis* marks the definitive shift from one mode of organizing global nature to another, as in the transition from Dutch to British world hegemony and the simultaneous transition from charcoal and peat to coal as the decisive energy source.

The central question today is whether the present conjuncture represents a *developmental crisis* of capitalism that can be resolved by establishing new worldwide conditions for accumulation, or whether we are now witnessing an *epochal crisis* of capitalism.

Capitalism as World-Ecology: Towards a Theory of Crisis

I take up these questions from the perspective of capitalism as ‘world-ecology’, and as a historical formation that has emerged and developed, through successive periods of restructuring and renovation, since the long sixteenth century, c. 1450–1640 (Wallerstein 1974; Arrighi 1994; Moore 2000, 2003a–c, 2007, 2008, 2009, 2010a,b). While capitalism as a world-historical formation – premised on the progressive removal of custom, state, institutional and other restraints on the endless accumulation of capital and the endless commodification of human and extra-human nature – is widely understood, capitalism as ‘world-ecology’ merits some explanation.

By ‘ecology’ and its cognates, I seek to transcend the Cartesian narrative of capitalism *and* ‘the environment’. Rather, I focus on the relations of capitalism

through the uneasy fractures and interdependencies of social and biophysical natures. I therefore borrow from the Greek root *oikos* (home or house), and speak in terms of ecological regimes, revolutions and crises, recalling the philosopher-botanist Theophrastus's term *oikeios* 'to indicate the relationship between a plant species and the environment' (Hughes 1994, 4). The *oikeios* is my term for that messy bundle of relations that give rise to the nature–society dialectic.

If neoliberalism is typically regarded as a bundle of social forces that acts upon the rest of nature, imposing its 'footprint' as the convenient metaphor has it, capitalism as 'world–ecology' signifies the differentiated unity of the production of nature and the endless accumulation of capital. Capitalism, in this perspective, does not *have* an ecological regime. It *is* an ecological regime – signifying those relatively durable patterns of class structure, technological innovation and the development of productive forces, organizational forms and governance (formal and informal) that have sustained and propelled successive phases of world accumulation since the long sixteenth century. Ecological regime refers to the historically stabilized process and conditions of extended accumulation; ecological *revolutions* mark the turbulent emergence of these provisionally stabilized processes and conditions. I therefore focus on the socio–ecological constitution of the strategic relations of historical capitalism, rather than the 'interaction' of social and biophysical essences. This constitutive dialectic manifests itself beyond the manifold 'changes in the land' commonly associated with environmental history: property relations, commodity-centred resource extraction, cash–crop agriculture, energy complexes and so forth. The production of nature–society relations has been every bit as much about factories as forests, stock exchanges, shopping centres, slums and suburban sprawls as soil exhaustion and species extinction.

Ecological regimes emerge through those market and institutional mechanisms necessary to ensure adequate flows of energy, food, raw material and labour surpluses to the organizing centres of world accumulation, but we should also attend to the production complexes that consume these surpluses, and set in motion new (and contradictory) demands upon the rest of nature. That is to say, the town–country antagonism – overlapping, but not to be confused, with the core–periphery divide – is the decisive geographical relation. Ecological regimes constitute a matrix of relations governing 'town' (consuming surpluses) as well as 'countryside' (producing surpluses). Foster's 'metabolic rift' (2000), then, is not merely a particular effect of capitalism but is constitutive of the capitalist mode of production. Every phase of capitalism *emerges through* a revolution in nature–society relations – new metabolic rifts, and much beyond – that creates new possibilities for the expanded accumulation of capital (Moore 2000).

What constitutes these possibilities? All great waves of capital accumulation have unfolded through a greatly expanded ecological surplus, manifested in cheap food, cheap energy and cheap inputs. The creation of this ecological surplus is central to accumulation over the *longue durée*. There is a dialectic between capital's capacity to appropriate biophysical and social natures at low cost, and its immanent tendency to capitalize the reproduction of labour power and extra–human natures. I will turn to this dialectic of the appropriation and capitalization of nature–society relations presently. First, however, we can ground the tension between these two moments in Marx's theory of *underproduction*.

It is often forgotten that Marx offered a theory of underproduction alongside one of overproduction. The achievement of the Industrial Revolution was to reverse the greatest problem of early capitalism – the *under*production of basic inputs, especially fuel, fibres and timber, for the centres of commodity production (Moore 2007, 2010a,b). The contradiction itself was not, however, abolished, but only checked. Is it possible that capitalism is moving towards a resurgence of the tendency towards underproduction? Let us hold this possibility as an open question.

Marx's theory of underproduction crisis – he calls it a 'general law' of accumulation – argues that 'the rate of profit is inversely proportional to the value of the raw materials' (1967 III, 111). The very dynamism of capitalist production leads the 'portion of constant capital that consists of fixed capital . . . [to] run significantly ahead of the portion consisting of organic raw materials, so that the demand for these raw materials grows more rapidly than their supply' (*ibid.*, 118–19). There is an important tension between the 'overproduction of machinery', and the 'underproduction' of raw materials (Marx 1967 III, 119). The great accomplishment of capitalism has, therefore, consisted in reducing the cost of inputs, while simultaneously expanding by orders of magnitude the material volume of commodity production – hence the centrality of the commodity frontier in modern world history, enabling the rapid mobilization, at low cost (and maximal coercion), of epoch-making ecological surpluses.

The tendency towards underproduction has therefore been checked over the past two centuries through the combined and uneven dynamics of geographical expansion and socio-technical innovation. It is something of an optical illusion that we usually associate capitalism's great ecological revolutions – commonly discussed in terms of successive agricultural and industrial revolutions – with increasing capitalization alone. The long history of 'capital-intensive', epoch-making innovations – above all, the early modern shipbuilding–cartographic revolution, the nineteenth century steam engine and the internal combustion engine of the twentieth century – has indeed been marked by the geographically specific concentration of capital in particular places, above all in the heartlands of the Dutch, British and American hegemonic regimes. And yet every epoch-making innovation has also marked an audacious revolution in the organization of global space, and not merely in the technics of production. *Thus, epoch-making innovations have joined together productivity and plunder in a world-historical act that drives down the share of world nature directly dependent on the circuit of capital.* The 'steam engine', for instance, was unthinkable without the vertical frontiers of coal mining and the horizontal frontiers of colonial and white-settler expansion in the long nineteenth century. The result is a (temporary) downward ratchet of the systemwide organic composition of capital – thereby providing a crucial condition for the revival of profitability – even as capital formation leaps forward in the metropolitan and hegemonic centres.

There are two key concepts here, the ecological surplus and the capitalization of nature. First, an ecological surplus does not refer to large or small amounts of 'stuff', but rather to a bundle of socio-ecological relations. There are four principal forms of this surplus: labour power, food, energy and non-energy inputs such as metals, wood and fibres. The relation between cheap food and the price of labour power is especially close. The key point, which can scarcely be overemphasized, is that 'cheap' food, energy and inputs are *cheap* to the degree that they issue a downward

revision of the systemwide organic composition of capital – the fixed, *and no less important*, circulating, moments of constant capital.

The relation to systemwide capitalization is crucial, for the ecological surplus is only partially produced through the circuit of capital. The ecological surplus is, rather, *delivered* through some combination of capitalized production (e.g. farm mechanization) and the appropriation of nature as ‘free gift’. Energy-intensive agriculture, for instance, develops by appropriating biophysical natures formed over long geological time (water and oil pumped from aquifers and fields). In this way, intensive capitalization and extensive appropriation form a dialectical unity.

If every phase of capitalism has emerged through a revolution in the ecological surplus, where today can such surpluses be found and produced? This is the indispensable question in ascertaining the relations between the (so-called) ‘economic’ and ‘environmental’ moments of the present crisis. We are living through the greatest economic downturn since the 1930s, or so we are told (Eichengreen and O’Rourke 2009). But how appropriate is the comparison with the Great Depression? The present world conjuncture, and its relative stagnation, or worse, in the delivery of food and energy surpluses, calls forth two other comparisons. The first is the era commonly associated with the early Industrial Revolution, and the progressive exhaustion of England’s agricultural revolution between 1763 and 1815, linked up with an agricultural ‘deceleration’ – marked by stagnating labour productivity, rising cereal prices and a new polarization of agrarian class structure – that reached from the Valley of Mexico to Scandinavia (Slicher van Bath 1963; Abel 1980; Jackson 1985). This marked the signal crisis of one ecological regime, and it threatened the rise of industrial capitalism (hence Ricardo’s fear that rising food prices would throttle industrialization). England, the breadbasket of *early* eighteenth century Europe, in the later eighteenth century saw food prices rise by 200 per cent, four times faster than the industrial price index (O’Brien 1985, 776) – a key moment of what I call a *developmental ecological crisis*. Land productivity could have been increased, given the best practices of the period, but only through labour-intensification, and this would have contracted the reserve army of labour, at precisely the moment when it was most needed for industry and empire. The solution was ultimately found in two great frontiers, which yielded two great sources of windfall profit. The first frontier was vertical, moving *into* the Earth to extract coal. The second was horizontal, moving *across* the Earth to produce wheat, especially in North America. When another ‘great depression’ arrived in the 1870s, the era’s rapid industrialization was possible on the basis of cheap food, delivered by the co-operative labours of both frontiers, at the same time as mass starvation in South Asia and China and genocide in North America.

It is also possible that the most appropriate comparison for the crisis of neoliberalism is the crisis of feudalism. This was an *epochal* crisis of nature–society relations (Moore 2007). The origins of today’s ecological crisis can be found in the responses of Europe’s ruling classes to the crises of the fourteenth century. There are striking parallels between the world-system today and a broadly feudal Europe at the dawn of the fourteenth century: the agricultural regime, once capable of remarkable productivity gains, entered stagnation; a growing share of the population lived in cities; expansive trading networks connected far-flung economic centres, and epidemiological flows between them; climate change (the onset of the ‘Little Ice Age’)

had begun to strain an already overextended agro-demographic order; and resource extraction, especially in silver and copper, faced new geo-technical challenges, fettering profitability and limited output. After six centuries of sustained expansion, by the fourteenth century feudal Europe had reached the limits of its development – for reasons of its environment, its configuration of social power and, *above all*, the relations between the two.

In short, my working proposition is that we can best discern the nature of the present global crisis – *including speculations on eco-catastrophe that have gained traction on the left* (Foster 2009) – by clarifying how we understand nature–society relations in the history of capitalism. Is today's crisis *developmental*, and therefore open to resolution through new forms of productivity and plunder, as occurred after 1830 in the British-led world-system? Or is it an *epochal* crisis that cannot be resolved within the logic of endless accumulation, and whose outcome is by definition unknowable? What better point of departure to engage these questions than the history of agriculture in the neoliberal era, evaluated through the cyclical movements and secular trends of the capitalist world-ecology from the long sixteenth century?

Capitalism and the Centrality of Cheap Food

For the greater part of six centuries, the relation between capitalism and agriculture has been a remarkable one. In contrast with all previous civilizations, capitalism organized a series of extraordinary expansions of the food surplus, through successive agricultural revolutions. The 'golden ages' of pre-capitalist civilizations invariably turned to crisis so long as cultivation remained in the hands of peasants, who were not subject to market discipline. Sooner or later demographic expansion undercut land and labour productivity, and along with it, the agricultural surplus available for commercial and manufacturing growth in the broader social economy. Such had been the case with feudalism (Moore 2003b).

In contrast, capitalism achieved its long-run economic expansion by means of imposing bourgeois property relations on the countryside, compelling the transition from peasant producer to capitalist farmer. With the transition to capitalism, the imposition of private property in land, backed by the power of the modern state (and its imperial formations), propelled a process of dispossession and differentiation that enabled rising labour productivity in agriculture and a rising food surplus. Vast reservoirs of labour power took shape to feed the satanic mills, and vast agricultural surpluses were mobilized to feed these workers. From the Dutch and English agricultural revolutions of the early modern era, to the family farm and Green Revolutions of the nineteenth and twentieth centuries, the bloody expropriations of capital have justified themselves on the basis of this signal achievement ('modernization').

The road to the modern world, it seems, has been paved with cheap food. As noted earlier, food, energy and inputs are 'cheap' to the degree that they are produced, and otherwise mobilized, at significantly lower costs than the systemwide average, and at significantly high volumes to *drive down* the costs of production for the system as a whole. The price of food is so pivotal because it conditions the price of labour. The great eras of capitalist development have always been conditioned on massive demographic expansion *and* massive proletarianization. The signal contribution of

agricultural revolutions to the course of capitalist development can be found here, in driving down the relative cost of food while driving forward proletarianization.

Every great wave of world accumulation, and every great ('hegemonic') power, has developed on the basis of far-flung reconstitutions of world-ecology, with agricultural revolutions at their centre. Does the present impasse – captured in popular discussions of the 'end' of cheap food and cheap oil (e.g. Roberts 2004, 2008) – represent the latest in a long history of limits and crises that have been transcended by capital? Is another agricultural revolution, comparable to those we have known in the history of capitalism, possible?

Or have we arrived at an epochal turning point in the relation of capital, capitalism and agricultural revolution?

We may consider the conditions for such an agricultural revolution from the standpoint of the four major ways in which the Left has engaged the Agrarian Question in the long twentieth century: the contributions of agriculture to capitalist development as a whole; the contradictions between capitalist agriculture and biophysical natures; the penetration of agriculture by capital, such that agro-ecological production has become increasingly dependent on the circuit of capital; and the role of peasantries and agrarian classes of labour in the struggle for democracy and socialism (Kautsky 1988; Byres 1996; Moore 2008, 2009; Bernstein 2010). In this essay, I concentrate on the first three moments, to argue for a way of seeing historical capitalism as an ecological regime. Situating recent world agricultural history in the neoliberal era (from the early 1970s) within the long-run and large-scale patterns of recurrence and evolution in the modern world-system, my intention is to present a series of guiding threads to open new discussions on the future of capitalism as a global socio-ecological formation – capitalism as not merely 'world-economy' but as *world-ecology*, joining together the accumulation of capital and the production of nature in dialectical unity.

NEOLIBERALISM AS ECOLOGICAL PROJECT: TOWARDS AN 'AGRICULTURAL REVOLUTION IN REVERSE'?

In the wake of skyrocketing food prices and worldwide food riots in 2008 (Holt-Giménez and Patel 2009), the question of agriculture occupies a central place in our thinking about the present crisis, and the future of capitalism. Even as food commodity prices on the world market declined (though still higher than 2004 levels), real food prices through the periphery remained high, or 'continue[d] to increase' into spring 2009 (Blas 2009b). The predictable consequence was rising official world hunger, topping the one billion mark for the first time, with at least twice that number suffering from 'micro-nutrient deficiencies' (Weis 2007, 12; Blas 2009a). It is an ominous parallel to the resurgence of chronic famine and food insecurity that characterized feudal Europe after the first signs of systemic crisis at the dawn of the fourteenth century; in less than a century, feudalism was done for as a world-historical project (Moore 2003b).

Agricultural revolutions in the capitalist world-ecology have accomplished two big things. First, they have yielded a quantum leap in the food surplus – it is a 'surplus', because the expanded body of use-values is sufficiently large to drive down the *systemwide* costs of reproducing labour power. This food surplus is one

moment of a broader ecological revolution that accompanies transitions from one phase of capitalism to another – revolutions that yield what I call the relative ecological surplus, whose signal contribution is the significant reduction of the value-composition of key primary commodities such as food and raw materials. Second, agricultural revolutions have been central to the successive rise of the Dutch, British and American hegemonies in capitalism. Hegemonies are ecological projects, and each great power wove together internal *and* external agricultural revolutions in the drive to world primacy.

It is difficult to see these two accomplishments in the history of neoliberalism. Historically, ascendant hegemonic powers have led an agricultural revolution that yielded a quantum leap in the delivery of cheap food to a critical mass of the world proletariat – the Dutch in the sixteenth and seventeenth centuries, the English in the seventeenth and eighteenth centuries, the Americans in the nineteenth and twentieth centuries (Friedmann 1978; Overton 1996; Brenner 2001; Walker 2004). These revolutions were, in Arrighi's sense of the term, 'organizational revolutions' (1994), unfolding at multiple scales and extending from innovations in the forces of production to new forms of credit and transport. The connection with the world proletariat is crucial. The chief determinant of the minimum wage threshold for any working-class household is the price of food and, therefore, the price of food is, on a systemwide basis, the chief determinant of value, *qua* abstract social labour. Food is, to recall the arguments of the previous section, 'cheap' to the extent that it reduces the 'value' of commodified labour power, and augments capital's capacity to extract surplus value.

Is the neoliberal world order – in the midst of a signal but not yet terminal crisis – leading capitalism towards what Braudel once called an 'agricultural revolution in reverse' (1972, 427), that is, towards a relative decline in labour productivity and the relative food surplus? Until the late twentieth century, every epoch-making 'economic miracle', as we have observed, rested upon an epoch-making agricultural revolution sufficient not merely to feed itself, but also to lead the world. Every world hegemony provided a new model of agricultural development: the Dutch Republic was the 'mecca' of agricultural knowledge for Europe in the seventeenth century (Moore 2010b). Later, the English and then the Americans would dispense worldwide, by means fair and foul, their agronomic wisdom to the rest of the world in the nineteenth and twentieth centuries (Kloppenburger 1988; Drayton 2001).

The world agriculture constituted by neoliberalism was highly successful in delivering cheap food, as Figure 1 suggests. In 2001, food had never been so cheap – even as US consumers faced rising prices for healthy food and falling prices for junk food (Patel 2007). By December 2007, food prices were at their highest in real terms since 1846, the year *The Economist* began keeping track (Buntrock 2007). It was a spectacular reversal of fortune.

What had happened? Beginning in the 1970s, and picking up steam with the debt crises of the early 1980s, the 'political determination of world agricultural commodity prices [that] emerged through the Uruguay Round negotiations' and into the WTO-era radically decoupled world market prices from production costs (McMichael 2005, 282). This was crucial to two major developments. First, and most importantly, world food prices dropped by 39 per cent between 1975 and 1989, and still further in the decade that followed (*ibid.*, 278; see also FAO 2009).

Figure 1 Cheap food and the neoliberal ecological regime



Source: FAO (2009).

Cheap food has always been indispensable to the revival of world accumulation, even in eras of financialization (Moore 2008, 2010b). Second, the radical decoupling of world price and production costs created major new opportunities for the concentration and centralization of capital in the agro-food sector, such that by 2000 just four corporations controlled '82 per cent of beefpacking [in the USA], 75 per cent of hogs and sheep, and half of chickens' (Greider 2000). By 2008, 'five corporations control[led] 90 per cent of the international grain trade, three countries produce[d] 70 per cent of exported maize, and the thirty largest food retailers control[led] one-third of world grocery sales' (McMichael 2009).

The unravelling of the cheap food regime (along with those governing cheap oil and metals) began in 2003 and reached an inflationary crescendo in 2008, signalling a decisive moment of neoliberalism's crisis. For this reason, following Arrighi, I would characterize the present conjuncture (c. 2008–15) as the *signal crisis* of neoliberalism as ecological regime. It is certainly true that neoliberalism lives on as a 'class project' (Harvey 2009), and as a mode of 'market-disciplinary regulatory restructuring' (Brenner et al. 2010). But these expressions of 'neoliberalization' are, in the final analysis, dependent upon the system's capacity to deliver cheap food, oil and inputs. Hence, signal crisis refers to the moment at which the ecological regime has reached its tipping point in the production of the relative ecological surplus, the mass of use-values (appropriation) relative to the demands of world value production (capitalization). A terminal crisis still awaits.

The crucial point is that each agricultural revolution moves beyond a series of modest technical adjustments that yield incremental gains to realize a *great leap* forward in the provision of cheap food, thereby enabling a revolutionary expansion (and subsequent, low-cost reproduction) of the world proletariat that accompanies a new long wave. Each agricultural revolution, therefore, has realized a *great leap* forward in the provision of cheap food. It is difficult to overstate the success, in capitalist terms, of the post-Second World War agricultural revolution, which opened in the mid-1950s with US Public Law 480 (1954) and Khrushchev's push to expand

Soviet cereal output (1953). The subsequent globalization in the 1960s of the 'Green Revolution' model – which I take as a convenient shorthand for the capital-intensive 'industrial agriculture' that developed first in the USA during the early twentieth century – was not only a pivot of American hegemonic leadership but also achieved a yield revolution unprecedented in human history. Between 1950 and 1990, global cereal output nearly tripled, propelled by a rise in 'grain yield per hectare . . . by roughly 2.4 times' (Weis 2007, 17). Meanwhile, world cereal trade more than tripled during 1952–72, and the real price of rice, maize and wheat dropped by 60 per cent between 1960 and the end of the last century (FAO 2002, 11; Warman 2003, 203). World market prices for staple foods fell steadily as world urbanization – a rough-and-ready index of proletarianization – proceeded at breakneck speed (Davis 2006). Even after the crises of the early 1970s, the vitality of the 'national farm sectors' created through the Green Revolution would provide strong yield growth for another decade and, after 1982, offered fertile terrain for conversion into neoliberal agro-export zones (McMichael 1997, 1998; Tilman et al. 2002). This postwar agricultural revolution ably meets our litmus test: a revolutionary expansion of the food surplus during a revolutionary expansion of the world proletariat.

For the agricultural revolutions of historical capitalism, modest gains in productivity are not enough. Today, food is not getting cheaper, even if we attribute some measure of the 2003–8 commodity boom to financial speculation (Ghosh 2010). It makes little difference, for world accumulation as a whole, if food, energy and raw materials are underproduced because of biophysical exhaustion, social unrest or speculation. As finance capital increasingly unifies world accumulation with the structures of everyday life (food, water, housing) – rendering these latter dependent upon the vitality of $M-M+$ through credit mechanisms – this suggests the need to view financialization and the commodification of nature as differentiated moments within the unity of late capitalism.

Globalizing malnutrition does not add up to a 'food crisis' (*pace* Magdoff and Tokar 2009.) So long as hunger can be corralled, and imposed on the very poorest of the world, there is no great problem. The great boom of the long twentieth century was constructed on the mass graves of the 'late Victorian holocausts' supervised by the British Empire, during the late nineteenth century era of financialization (Arrighi 1994; Davis 2001). What matters is the price of food in the heartlands of proletarianization, where there was no food crisis in the late nineteenth century. Indeed, world cereal prices declined sharply, propelled by genocide, 'railroadization' and the first serious mechanization of agriculture (Friedmann 1978; Kautsky 1988; O'Rourke 1997).

Where will capital today find the conditions for another such era of cheap food? Neoliberalism pins its hopes for agricultural revolution on biotechnology, associated with all manner of the 'new enclosures' (Shiva 1997; Rifkin 1998; Weis 2007; Cooper 2008). It fits the classic model of agricultural revolution, in so far as it effects a redistribution of income (further differentiating classes of farmers), is enabled by the property-making and -securing capacities of states and state-like institutions, and constitutes a promising opportunity for accumulation by some sectors of capital. It *does not* fit the model, in so far as it has yet to deliver a yield boom sufficiently large to create (in concert with cheap energy and cheap inputs), the conditions for a new systemic cycle of accumulation.

The globalization of agricultural biotechnology has failed to slow the progressive decline in yield growth worldwide, now for the better part of a quarter-century (Tilman et al. 2002). If agricultural revolutions in the modern world have justified their bloody expropriations on the basis of socio-technical innovations that maximized labour productivity in agriculture, and drove down the cost of basic foodgrains, the so-called biotech revolution has made little progress. A decade of research has yielded the conclusion that agricultural biotech has done little to improve intrinsic yields (Benbrook 2001; Gurian-Sherman 2009) – even prompting Monsanto to announce plaintively that ‘the main uses of GM crops are to make them insecticide- and herbicide-tolerant. *They don’t inherently increase the yield.* They protect the yield’ (quoted in Ritch 2009, emphasis added). As it turns out, Roundup Ready® crops, soy above all, are not doing much to *protect* yield either, as ‘superweeds’ have evolved to survive the onslaught of the famed herbicide (Benbrook 2009).

This ‘*superweed effect*’ marks one aspect of agriculture’s *differentia specifica* in Marx’s important – if too often neglected – argument, noted earlier, that the ‘overproduction’ of machinery (fixed capital) tends towards the ‘underproduction’ of raw materials (circulating capital). Rising costs of energy and inputs used in a given production cycle reinforce the tendency towards a declining rate of profit inscribed in rising mechanization. As capital invested in machinery overtakes that spent on wages, therefore, the very productivity gains achieved by mechanization and standardization set in motion widening demands for circulating capital (inputs). But the production of energy, wood, metals, fibres and other inputs is rooted in socio-ecological processes that do not respond quickly or easily to market signals. The world oil sector, for example, has been characterized by underinvestment, relative to rising demand for cheap energy, since the mid-1980s (IEA 2008). And in agriculture, rising fertilizer prices in 2003–8 tended to undermine farm-level profitability.

But there is more to this story. In agriculture, relative to factory production, another element is introduced. Efforts to increase labour productivity have led, in the neoliberal era, to new strategies that seek to discipline biophysical nature at a cellular and even genetic level. This is the ‘transition from the formal to the real subsumption of nature to capital’ (Boyd et al. 2001). The problem for capital is that biophysical natures evolve faster than the capacity of capital to control them. The development of new GMO varieties is not delivering a new yield revolution (Gurian-Sherman 2009); moreover, there is a growing tendency for farmers to turn away from these varieties in some important regions, such as Brazil’s Mato Grosso (Reuters 2009).

Capitalism today confronts the *exact* opposite of its early modern bounty. The rise of capitalism was greatly facilitated by a series of ‘yield honeymoons’ through which the introduction of Old World crops into the New World (sugar), and New World crops into the Old World (potatoes), provided massive yield windfalls (Dark and Gent 2001; Moore 2007). The advantage of a yield honeymoon is that very little capital need be set in motion to produce very large amounts of food. What capital wants, above all, is to invest a little and to gain a lot: a firm wants minimal capitalization to secure its maximal competitive position. Historically, the secret of capitalism’s success has been to maintain strict limits on the extent of capitalized nature. Capital’s first preference is to appropriate nature, rather than to produce it

through the circuit of capital. But the opportunities for appropriation, sufficient to resolve neoliberalism's crisis, are not expanding, but in fact contracting – and in agriculture this contraction owes something to the superweed effect. When Neil Smith sees the production of nature entering a new phase, characterized by 'capitalization all the way down' to the genetic relations of life itself (2006, 21), he suggests that this may provide the conditions for a new phase of accumulation. I am not at all certain that this follows. While pockets of highly capitalized primary production have always thrived in the modern world-system, a *decline* of the ecological surplus has always issued from the rising capitalization of world nature. The point of departure for every great wave of accumulation has been the radical enlargement of the geographical arena for commodity production and exchange, thereby extending the realm of socialized nature *appropriated* (but not yet subsumed) by capital.

The relative scarcity of external frontiers underpins a central feature of our times. Not only 'cheap oil' but also 'cheap food' may now be finished, a view not limited to critics of the agro-food system. The OECD forecasts real price increases of 10–35 per cent over the next decade for a basket of key food commodities, in a projection grounded in the dubious expectation that yield growth will follow the 'historical trend' of 1960–2000 (OECD 2008; OECD/FAO 2008, 47). The UN Environmental Program's recent report on the 'environmental food crisis' (Nellemann et al. 2009) predicts, *inter alia*, climate change-driven reduction in cropland by 8–20 per cent by mid-century; mounting pressures on aquifers and above all glaciers, signalling looming water scarcity; the proliferation of invasive species, and rising biological resistance to pesticides and herbicides; rising fertilizer prices, and their declining effect on yields; escalating competition for arable land from agrofuels (already one-third of the US maize crop in 2008); and, perhaps most ominously, 'an absolute decline in the productive land area (Net Primary Productivity) across 12 percent' of the planet, with the areas most affected home to nearly one-fifth of world population – all of which will be amplified still further by climate change and the mounting 'risk of abrupt and major irreversible changes' (*ibid.*, 40, 43). The progress of global warming is, moreover, already implicated in the yield suppression of major cereal crops (Cline 2007).

This is bad news for a world-economy undergoing the most serious depression since the late nineteenth century, when cereal prices *declined* by nearly 27 per cent between 1870 and 1914 (O'Rourke 1997, 789), underwriting a rapid shift in the global centre of gravity from Britain as workshop of the world to the USA as the world's assembly line. What is the analogous process for today's workshop of the world? From where will China's several hundred million industrial and urban workers be fed?

I am not at all sure that the old answers to this question apply, if the history of capitalism is any guide. The sixteenth century Dutch grew rich thanks to cheap grain from Poland's Vistula; the nineteenth century English had Ireland, the Caribbean and the American Midwest. When the USA came to world power, it had the Midwest, plus the American South and California, and Latin America. Decisive food surpluses were won in all cases from untapped frontier zones, coupled (increasingly) with the productivity-maximizing genius of capitalism. Even South Asia's Green Revolution owed much to the appropriation of 'vertical' frontiers: plentiful aquifers at home and relatively cheap energy supplies (for fertilizer) abroad. Cheap water and

cheap energy *qua* fertilizer are rapidly disappearing today (Shah et al. 2003; Schill 2008). And while biotechnology and biopiracy through the 'new' enclosures have succeeded in greasing the wheels of world accumulation since the 1990s, they have done little to achieve what all previous agricultural revolutions had done: create the conditions for a long-term relative decline in food prices. If the crisis of neoliberalism today is in fact a *developmental crisis*, one open to resolution within the capitalist mode of production, we would expect to see an agricultural revolution taking shape in the most dynamic new centre of accumulation, China. But following the burst of productivity and aggregate output in the 1980s, there is little to suggest that China is on the brink of an agricultural revolution that will not only feed the world, but *lead* capitalism to a new golden age (Smil 2004).

The transition from 'old' to 'new' agrarian questions during the 1970s, suggested for very different reasons by Bernstein (2001) and McMichael (1997), points to the exhaustion of capitalism's agro-ecological frontiers, set in motion during the long sixteenth century. While there are still forests and tracts of 'underutilized' land to enclose and exploit, *today's* frontiers are but drops in the bucket relative to the demands of value accumulation. Frontiers are not merely places 'out there' (and out of time) but are constituted by the varying logics of systemic reproduction in its successive developmental phases. This closure of the 'Great Frontier' (Webb 1964) marks an epochal transition in the history of capitalism. The closure of resource, labour and waste frontiers has cut off a key avenue of capital's escape from the rising costs of production.

The rising capitalization of world agriculture – through which the farm becomes the agro-ecological pivot of 'downstream' and 'upstream' commodification – not only amplifies the tendency towards a declining rate of profit, but in equal measure amplifies the pressures to escape it, through efforts to extend the frontier of 'technical control' (Edwards 1979). The rise of American capitalism in the late nineteenth century implied, and indeed necessitated, a world-historical shift from the primitive accumulation of botanical knowledge to the *expanded reproduction* of botanical knowledge, pioneered by US land-grant agricultural colleges, and globalized after the Second World War through the CGIAR network of International Area Research Centres (Kloppenborg 1988). There is, then, a longer history to the efforts of Monsanto, *inter alios*, to centralize agricultural knowledge in the hands of capital and displace farmers' long accumulated and tested 'craft' knowledge of local conditions and practices based on it (Glenna 2003; Stone 2007). In this light, the Green Revolution, with its recipes for growing (this much seed, this much fertilizer, this much water and so forth), may be re-read as the agro-ecological moment of the control revolution that enabled the rise of giant industry, and the wholesale displacement of skilled with semi-skilled labour, characteristic of the American mass production regime (Davis 1985) – itself an ecological project of the highest order. In so doing, leading agencies of agrarian capital (agribusiness) move at cross-purposes to capital as a whole, undermining the very flexibility achieved through the nineteenth century's family farm revolution in North America, which relaxed the operation of the law of value through the deployment of family rather than wage labour (Friedmann 1978). The erosion of this flexibility certainly offers a short-run advantage to capital, but undermines a socio-ecological pillar upon which the remarkable expansion of the long twentieth century and its agricultural revolution rested.

Capitalization is not alchemy. The socio-technical innovations propelling modernity's successive agro-ecological revolutions were never able to create something out of nothing. The world-ecological storehouse of such stimuli is not inexhaustible – new energy sources, scientific regimes, technical packages and organizational forms cannot be simply conjured out of the productivity-maximizing magic of bourgeois ingenuity. *These stimuli must come from somewhere.* And so it is not only the specific stimuli that are exhausted – as in the chemical-technical repertoire of the Green Revolution – but also the underlying vitality of the specifically capitalist *oikeios*. These stimuli have pivoted on the relation between the variable forms of bourgeois territorial and property relations, technical dynamism and the availability of un- or undercapitalized nature. The English agricultural revolution of the long seventeenth century – our classic frame of reference – was not 'simply' the expression of convertible husbandry, new drainage systems and so forth, but could only proceed on the basis of a double movement of geographical expansion: an 'inner' conversion of nitrogen-rich pasture into arable land (therefore opening an expansive nitrogen frontier) within England (Overton 1996); and an 'outer' conversion of the English Caribbean into plantation monocultures, in sugar above all (Dunn 1972). English, then British, capitalism thrived on the basis of this double movement. The Industrial Revolution took shape on its basis, the first movement issuing labour surpluses (Brenner 1976), the second, capital surpluses (Blackburn 1997).

Sometime after 1760, this 'first' agricultural revolution was showing clear signs of exhaustion. Within England, per-acre yield growth stagnated after mid-century, and most of European agriculture experienced the same effect (Slicher van Bath 1963; Abel 1980; Clark 1991). Although Pomeranz does not see this as a capitalist crisis, he quite fruitfully posits this impasse in historical-relational rather than abstract-materialist terms – that is, from the standpoint of socio-ecological organization rather than biophysical properties narrowly defined:

[P]er-acre and total yields from arable land remained flat and the threat of decline constant, until Britain began mining, importing, and later synthesizing fertilizer mostly after 1850. . . . [A]lthough the English studied continental practices, classical agricultural manuals, and their own experiments very intently, much of what they learned about how best to maintain soil fertility while increasing yields was not actually applied in England, because it involved highly labour-intensive methods and English capitalist farmers . . . were intent on labour-cost minimization and profit maximization. The methods they adopted instead, which raised labour productivity, represented a *fundamental break with much of the literature on best farming practices and actually interfered with preserving soil fertility in many cases.* (2000, 216–17, emphasis added)

The problem was not that 'natural limits' had been reached, but rather that what appeared as a biophysical impasse was itself a limit of capitalist relations. Pomeranz's explanation focuses on the calculations of capitalist farmers, but may be reinterpreted from the standpoint of capital as a whole. Until off-farm phosphates became available after the Napoleonic Wars (Thompson 1968), the only way to significantly raise land yields was through labour-intensification. But this was precisely the moment when such labour supplies were most needed, to propel both the industrialization drive and to meet the manpower demands of the war.

Is it possible that the neoliberal ecological regime has entered a phase of its development broadly analogous to the crisis of early capitalism's ecological regime in the eighteenth century? Or does the crisis run even deeper? As a phase of capitalism, neoliberalism owed its very existence to the yield windfalls of the Green Revolution – superficially 'technical' windfalls themselves, premised on the disintegrating effects of market discipline imposed through state power. These windfalls were famously set in motion in India in the later 1960s, but with important forerunners in Mexico and the USA decades earlier (Wright 1990; Perkins 1997). Like every agricultural revolution before it, the Green Revolution of the 1960s and 1970s *increased* the relative ecological surplus, through the judicious (if brutal) reconfiguration of peasant ecologies, especially in South and South-East Asia (Griffin 1974; Shiva 1991). In one sense, this had long been the pattern, as agricultural revolutions had increased the ecological surplus through the appropriation of nature's free gifts, looking backwards from California and the American Midwest in the first half of the twentieth century (Kloppenborg 1988; Walker 2004) to Europe in the later nineteenth century (van Zanden 1991), the American Midwest in the mid-nineteenth century (Cronon 1991), and the English and Dutch agricultural revolutions of the seventeenth and sixteenth centuries (Overton 1996; Brenner 2001), alongside contemporary plantation revolutions, in sugar especially (Moore 2007).

In another sense, however, the Green Revolution did not fit the pattern, prefiguring the neoliberal agro-ecological impasse today. It enjoyed a much lower biophysical 'rent' than its forerunners – most recently, the agro-industrial revolution of the American Midwest in the nineteenth century – and this goes a long way to explaining the high rate of investment and technical change in the later period. Relative to the worldwide 'ecological crisis' of peasant societies in the later nineteenth century (Wolf 1969), the ecological revolution set in motion during the late 1960s represented an epochal leap forward in the capitalization of agro-ecologies worldwide.

In contrast to the neoliberal era, the late nineteenth century represented an aggregate *decline* in the capitalization of world nature – the absolute extension of commodity production and exchange has tended to obscure the extent to which minimal capital investment met with maximal imperial power to realize the epochal appropriation of biophysical surpluses without (yet) capitalizing their delivery. Vast new socialized, though not yet capitalized, ecological formations were drawn into the matrix of accumulation. By compelling peasant producers throughout the new peripheries to sell 'without regard to price of production' – as Engels observed in the midst of the process (in Marx 1967, III, 726) – such appropriation relative to capitalization contributed significantly to the rising ecological surplus of the late nineteenth century.

The relation was reworked but not fundamentally remade in the long era of the Green Revolution. It was an era that emerged first in the global North. The commercial introduction of hybrid maize in the USA in the mid-1930s promised not only rising yields per acre, and rising capitalization through mechanization and skyrocketing fertilizer (and then pesticide) use. Hybrid maize marked an early, pivotal moment in capital-oriented biological innovation. By crossing inbred lines of maize whose seed produced high yields but could not be reproduced, American seed companies severed the age-old connection between seed and

grain (Kloppenborg 1988, 91–129). Hybridization thus married bio-technical control to the coercive dispositions of market competition, chaining metropolitan farmers to the ‘vicious cycle . . . [of a] technological treadmill’ and accelerated class differentiation (Kloppenborg 1988, 119; Glenna 2003).

The same dispositions played out later in the global South. Far from simply a technological marvel of new seeds and new chemicals, the appropriation of the best ecological spaces (good soil, good water) was necessary for the realization of the socio-technical visions of the Green Revolution. A big part of the reason why the Green Revolution was so successful (that is, *where and when* it was successful on its own terms) was that it imposed cutting-edge technology on regions where the value of labour and land was very low, driving down food prices and therefore, all things being equal, the cost of variable capital. (In other words, cheap food relieved pressure on capital’s wage bill, attenuating the falling rate of profit.) At the level of appearances, we are treated, then, to something of an optical illusion – a new stream of capital inputs leads one to think the Green Revolution in terms of capital-intensity. But in so far as this ‘revolutionary’ project appropriated, *at little or no cost to capital*, quality land, access to water and labour power, the value-composition of yields was in fact very low, and therefore highly profitable. The revolutionary achievements were made through plunder as much as through productivity.

Amongst the secrets of capital accumulation over the *longue durée* has been the progressive (and always contested) conquest and absorption of human and extra-human nature whose reproduction was either relatively, or entirely, free from the law of value. The contradiction in historical capitalism has been simultaneously to preserve and create – and in the same motion, to undermine and appropriate – the reproduction of ecologies (as *oikeios*) relatively autonomously from the circuit of capital. Left ecology has illuminated the ongoing transition from the formal to the real subsumption of (extra-human) nature to capital (Boyd et al. 2001; Smith 2006), but has yet to grasp fully how the rising capitalization of nature proceeds on the basis of the relative exhaustion of the conditions of production. So, for example, soil exhaustion is ‘fixed’ through rising capitalization in the form of fertilizers, while fertilizers themselves work only for so long before provoking pest invasions, escalating pesticide use, which creates new resistances, and so forth. The upshot is that the *rising capitalization of nature creates a world-historical situation of rising production costs stemming from the degradation of the conditions of production*. Rising socio-ecological exhaustion and rising capitalization are two sides of the same coin.

At the heart of the argument here is that the Green Revolution constituted a new phase in the capitalization of global nature.² As such, we would expect to see an epoch-making expansion of the relative ecological surplus, at the beginning of any revival of world accumulation, in terms of both extra-human nature (for example, grain or energy surpluses available for sale at low cost), and the mobilization of human nature *qua* relative surplus population. Such revolutions yield a double windfall: cheap, extra-human resources to maximize yields (and minimize

² In sharp contrast to the ‘new imperialism’ of 1873–1914, when capital’s appropriation of global nature (in the new colonies, in the white settler zones etc.) outran the capitalization of nature. This was true even in North America, with its massive appropriation of land, water and millennia of ‘stored’ but easily exhausted soil fertility.

their value component), thereby driving down food prices relative to those of industrial goods; and expanding the reserve army of labour through mechanization, labour-intensification and the differentiation of peasantries. As we have seen, the period 1980–2000 offered the lowest world market prices for food in world history, accompanied by the extraordinary expansion of the global working class. Freeman (2005) thinks that nearly 1.5 billion workers ‘from China, India, and the former Soviet Union entered the global labour pool’ in these decades. Even allowing for exaggeration in this figure, these accomplishments reduced the cost of labour power to global capital, and therefore counteracted the tendency towards declining profitability. In the middle run of 25–35 years (roughly the *durée* of neoliberalism), we would expect to see two contradictions within agriculture come into play, gradually eroding the mechanisms for delivering (or even sustaining) an ecological surplus sufficient for expanded accumulation. On the one hand is the rising organic composition of capital at a systemwide level. This tendency has progressed farthest in the USA, where the rising energy throughput of agriculture coincided with an avalanche of farm bankruptcies, registering faltering profitability at the ‘enterprise’ level after the 1970s. By 2004, just 3.4 per cent of US farms produced over 45 per cent of output by value, close to doubling the output share of the largest farms in the 1970s (MacLellan and Walker 1980; Hendrickson et al. 2008, 311). This tendency of farm concentration underpins the high rates of profitability enjoyed by agribusiness in the neoliberal era (McMichael 2009).

On the other hand, the very escalation of rising energy throughput – declining energy ‘efficiency’, if this is the right word for it (Pimentel et al. 1973, 2008) – can be understood as, first, a farm-level response to the coercion of finance capital, which demands rising productivity in relation to an average rate of profit determined in great part by non-agricultural enterprises, and increasingly the financial sector (M–M+); and, second, the relative exhaustion of neoliberal capacity to govern biophysical natures. The latter has assumed two principal forms to date: escalating resource depletion in water and soil especially, partially masked by nitrogen fertilizers; and the creative response of extra-human nature to the disciplines of capitalism, of which the ‘superweed effect’ is emblematic. Indeed, given the strongly bound coevolution of superweeds with GMO soy, we may soon come to understand the rise of the superweed as a world-historical event.

The post-1971 financial expansion – which represents a multiplication of systemwide claims on the future ecological surplus – propelled a radical expansion of property claims on the genetic diversity of the biosphere. This is not new, and in a broad sense this too is a cyclical phenomenon of the world-economy. The ‘primitive accumulation of botanical knowledge’ has been with us since the long sixteenth century (Brockway 1979; Kloppenburg 1988; Cañizares-Esguerra 2004). What is new, however, is neither enclosure, nor its latest incarnation *qua* ‘biopiracy’, but the whole spectrum of efforts to rework *and control* nature at a genetic level. Neoliberalism has joined rapid financialization with transitions from the ‘formal’ to the ‘real subsumption of nature to capital’. And so we have moved from Captain Hook to Dr Frankenstein in modernity’s production of nature.

Whether or not a biotech revolution will provide a way forward remains uncertain (see Kloppenburg 2010; Wield et al. 2010 – this issue). Gurian–Sherman (2009, 2), in the first comprehensive survey of biotechnology’s aggregate yield

effect, finds almost all gains in operational yields and not intrinsic yields (which ‘may also be thought of as potential yield’). Even if water and land constraints could be overcome through new genetic–chemical combinations – and the ‘water question’ may well be more serious than commonly recognized (Gleick 2008) – the very capital- and energy-intensive basis of late capitalist agriculture creates an even more serious constraint on its capacity to raise yields significantly. The technical control regime – in this instance, the control of weeds and pests – promises to induce the evolution of more resistant pests and pathogens (Ruttan 2002).

There is, then, a ‘feedback’ contradiction at play here. On the one hand, capital must realize an *epoch-making* expansion of the relative ecological surplus, manifested as a massive expansion of ‘cheap’ food, energy and materials. On the other hand, the very (capital-intensifying) strategies to enable such an expansion will enclose those small zones of undercapitalized nature that still exist, and will intensify the effort to fragment (and discipline the fragments of) global nature. Braverman’s illumination of capital’s drive to reduce concrete labours into ‘universal and endlessly repeated motions’ might well be extended to the *objects* of human labour as well (1974, 125). The drive to reduce extra-human nature to an ‘interchangeable part’ (*ibid.*) – that is, fragments – is, equally, an immanent feature of capitalist development: ranging from the ‘forest-equivalents’ of seventeenth century European forest laws (Moore 2010a,b) to the imposition of ‘extraordinary regular cadastral grids’ on the landscapes of North America, Australia and elsewhere (Brayshay and Cleary 2002, 6) to the manipulation of genetic material and the genomic mapping that it implies (Rifkin 1998).

Given the contraction of opportunities for appropriation, frontier expansion – the first movement – implies an escalation of class and imperial projects to ‘reserve the exclusivity of access to these resources’ (Amin 2008), and hence of costly social and geopolitical tensions. The second movement of capitalization *qua* socio-technical innovation is already generating a bundle of unpredictable responses, the superweed effect. The very strategies that seek to control any specific nature-fragment undermine the middle-run conditions through which productivity gains and predictability can be realized.

For this reason, I am not much concerned with the ecological ‘overshoot’ preoccupations of much green, and even red–green, thinking these days (Catton 1982; Foster 2009), not because overshoot is a poor description, but because it is not much of an explanation. The crucial issue, from the standpoint of the *longue durée*, is that the ‘time–space compression’ central to the accumulation of capital both depends upon, and drives ever faster, the time–space compression of biophysical natures. There is a dialectic here: in historical capitalism, extra-human nature evolves much faster than the social relations that seek to govern it. It is the very dynamism of the system creates the mirage of suspending the dialectic. And yet for all the hopes pinned on this mirage the biophysical moment is increasingly unpredictable and defies efforts to discern impending qualitative shifts with any degree of certitude (Scheffer et al. 2001).

As capital comes to circulate through (and not merely around) biophysical circuits, the faster these ecological revolutions move from liberating to imprisoning accumulation. Here is the political ecology of Nature as ‘opportunity’ and ‘obstacle’ – an enabler of, and hindrance to, capital accumulation – in successive ecological regimes (Mann 1990; Boyd et al. 2001). Thus each new ecological regime takes less time than

its predecessor to close the circle. This reflects two contradictions. First, there is the acceleration of turnover time as capital penetrates primary production. This is the transition from the 73-day chicken in 1955 to the 42-day chicken in 2005 (Boyd 2002, 637; Weis 2007, 61). We find the second in the 'taming cycle' (Wallis 2000), with the tale of the soybean and the superweed. The two moments find unification in Patel's quip that chickens are now 'soy with feathers' (2007, 212). Every leap forward in labour productivity (more chickens per working hour) also represents a leap forward in toxification (more poisons per dollar) and the creative responses of extra-human nature to the disciplines of capital (more weeds per hectare).

This inner logic of capital – its tendency to dissolve socio-ecological particularities and reconstitute them as 'interchangeable parts' (e.g. cadastral grids, standardizing hogs, green beans, and hamburgers, patenting genes) – tends to enable the accumulation of capital for a time, but, in the absence of uncapitalized nature, is unsustainable *within the logic of capital accumulation itself*. The temporal moment is crucial, for the rising capitalization of nature works within established boundaries by accelerating the appropriation of Marx's 'original sources' of wealth, labour and land (1976, 636–8). This acceleration poses one set of contradictions through the overproduction of machinery and the underproduction of inputs. Another, perhaps more destabilizing, set of contradictions emerges through the control efforts that seek to render more predictable the relation with the rest of nature but, over the middle run, create conditions of spiralling *un*predictability.

BY WAY OF CONCLUSION

For the better part of two centuries, capitalism 'as world-ecology' has produced abundance, not scarcity. For this reason it is easy to forget – even on the Left (e.g. Buck 2006) – that the history of capitalism has always been shaped by an explosive dialectic of overproduction *and* underproduction. The technical dynamism of the capitalist mode of production has obscured the former only through an extraordinary and 'long' twentieth century of appropriating, enclosing and otherwise mobilizing with minimal capital outlay, the 'buffers' of soil, water and air. These buffers are now gone (McNeill 2000, 359). This dialectic of productivity and plunder works so long as there are spaces that new technical regimes can plunder – cheap energy, fertile soil, rich mineral veins. Agricultural revolutions have been a decisive part of the always-contingent 'solutions' to underproduction, enabled by the capitalist appropriation – along with capitalized production – of cheap water, labour and energy. These agricultural revolutions have been a pillar of capitalism's global ecological fix strategy, weaving together horizontal conquests (new continents absorbed) and vertical enclosures (new mineral veins tapped or coalfields mined). So long as these fixes expanded opportunities for appropriation *faster* than they demanded capitalization, the ecological surplus expanded, and world accumulation revived. Capitalization remains indispensable – indeed, it becomes more crucial over time – but only by accelerating the exhaustion of the very conditions that sustain accumulation.

Capitalization can do its work only to the extent that a rising quantum of biophysical nature can attach to the same level of capital investment. This is the inner contradiction of the specifically capitalist ecological regime – the capitalization of world nature tends to rise faster than the opportunities for appropriation,

reducing the ecological surplus. This manifests in rising costs of production in agriculture, energy production and other primary sectors. And this can only be counteracted by liberating new reservoirs of socialized natures – rivers, natural gas fields, peasant societies – for the accumulation process. The relative ecological surplus falls as the capitalization of global nature proceeds. This is one of the chief ways in which capitalism not only ‘develops’, but *ages*. Today, there surely remain ecological spaces relatively untouched by the violence of the commodity form. But their relative weight in the world-system is incomparably lower today than it was in 1873, or even 1973.

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