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Sugar and the Expansion of the Early Modern World-Economy

Commodity Frontiers, Ecological Transformation, and Industrialization*

Jason W. Moore

This article attempts to restore and operationalize the concept of the frontier for the study of world capitalist expansion and its structural tendency towards environmental degradation. World-systems analysts have paid considerable attention to the ways in which the world-economy expands. The bulk of this work has been given over to the study of long waves, the reorganization of production units, state-formation, and other important processes. The ecological dimension, though acknowledged from time to time, has been underemphasized. I will trace the development and expansion of sugar cane production and trade in order to illustrate the centrality of environmental dynamics as a way of rethinking the early modern history of capitalist expansion. The history of sugar production and trade is well-known. Despite the existence of a vast literature, however, the environmental history of sugar has not been given the attention it deserves, nor has the link between ecological transformation and the expansionary logic of world capitalism. My goal is to suggest ways of rethinking early modern capitalist expansion as a *socio-ecological* process.

When I speak of frontiers, I am building on world-system studies of “incorporation” (see Hopkins et al., 1987; Wallerstein, 1989: ch. 3). The term frontier is overused. It has rarely been employed usefully in historical social science. Nonetheless, I think it can be

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reconceptualized satisfactorily within the world-systems paradigm. The concept of the frontier has been employed by historical sociologists engaged in regional studies, but has not been theorized adequately. Thomas D. Hall, for instance, defines a frontier as the area “where . . . incorporation occurs” (Hall, 1989: 24). In her otherwise brilliant study of Southern Appalachia, Dunaway (1996a) does much the same, treating the frontier simply as a zone of incorporation. This conceptualization does not distinguish the incorporation of the Americas from Asia and Africa, where strong state structures impeded full incorporation until the nineteenth and twentieth centuries. Whereas incorporation studies have focused on fairly general world-systemic processes and social transformations within particular regions, I wish to draw attention to the ways in which the production and distribution of *specific* commodities, and of primary products in particular, have restructured geographic space at the margins of the system in such a way as to require further expansion. To this end, I suggest the concept of the *commodity frontier*.

COMMODITY FRONTIERS

The idea of the commodity frontier derives from the world-systems concept of the commodity chain, which “refers to a network of labor and production processes whose end result is a finished commodity” (Hopkins & Wallerstein, 1986). Although the usual approach to the study of commodity chains is to *begin* with the finished product, the task of tracking frontier expansion requires a focus on relatively unfinished, “raw” materials; a full analysis would require a subsequent backtracking, which is outside the scope of this article. The point of commodity chain analysis is two-fold: 1) to determine the boundaries and shifting configuration of the world-economy’s interdependent division of labor; and 2) to analyze shifts between core, periphery, and semiperiphery over time according to each zone’s retention of surplus value. While state actors attempt to shape the system’s division of labor to their advantage, the primary organizing mechanisms are commodity chains, whose operations are by definition transnational. This approach permits an end run around traditional conceptions of frontier expansion, which accept the nation-state or imperial sphere as the primary unit of analysis rather than the world-economy as a whole.

The existence of multiple commodity frontiers in the Americas—sugar, silver, timber, cattle, foodstuffs, cotton, tobacco, furs and deerskins, fisheries, etc.—allows us, first, to track not only capitalist expansion but also the unevenness of that expansion. This helps correct the impression of many critics of the world-systems perspective, who rightly argue that the transition to capitalism has assumed radically different forms in different places, but wrongly contend that world-systems analysis is incapable of theorizing this diversity. Secondly, it provides a way to link up relatively abstract processes such as long waves with relatively specific processes such as commodity production and labor relations in particular places. The concept of the commodity frontier, moreover, sheds light on the ways in which place-specific commodity production shapes and is shaped by the socio-spatial expansion of the law of value—ongoing primitive accumulation—under which people are forced to “sell to survive” (Moore, 1997). This approach permits a deeper examination of how the world-economy and local ecosystems interact to determine the *rate* of capitalist expansion.¹ Thirdly, because commodity frontiers, especially sugar, required numerous capital inputs unavailable at the immediate point of production, the concept provides a more specific theorization of the simultaneous deepening and widening of the system’s social division of labor. In short, the commodity frontier gives meaning to the concept of the “multiplier effect” in terms of spatial expansion and the global reach of the law of value. And fourthly, because the most significant commodity frontiers were based on the exploitation of the environment—sugar, silver and gold mining, tobacco, grain, among others—the concept allows an exploration of the interrelationships between production in one *place*, and the expansion of capitalist *space* in general. I must add that commodity frontiers constitute the foundation of a broader world-historical category²—the *frontier mode* of capitalist expansion—the primary arena

¹ For the relationship between long waves and the advance of settlement on the frontier, see Earle & Cao (1993).

² It is of course true that there were many instances of capitalist expansion, in the New World and elsewhere, which did not hinge directly upon commodity production. Certainly, religious missions, military colonization, utopian communities, etc., cannot be chalked up to commodity production in a simple way. In addition, preemptive colonization has been an important feature of imperialism since the sixteenth century (Hall, 1989; Dunaway, 1996a). That said, the primary impetus for preemptive colonization came from the competition over the fruits of resource exploitation and profitable trade

of which was the Americas. I will touch briefly on this latter concept in the conclusion.

The frontier has been such a slippery category because it refers simultaneously to a certain kind of socio-spatial movement *and* to a certain kind of place—that is, the term “frontier” refers both to the “space-of-flows” *as well as* to the “space-of-places.” The two dimensions of the frontier mode may be captured in the following formulation. A frontier is a *zone beyond which further expansion is possible* in a way that is limited primarily by physical geography and the contradictions of capitalism rather than the opposition of powerful world-empires. The frontier is a specific kind of space defined by the forward movement of the (capitalist) system. Further expansion is possible so long as there remains uncommodified land, and to a lesser extent labor, “beyond” the frontier. Where the external barriers to capitalist expansion initially outweigh the internal ones—as in Africa or Asia during the early modern period—we must speak of borders and not frontiers.

Commodity frontiers were profoundly transformative of land and labor because they were often highly *industrial*. In particular, sugar production and refining, and silver mining were among the most industrial activities of the early modern world-economy (see Mintz, 1985; Bakewell, 1987). As the world-systems school has long maintained, there have been numerous phases of industrialization, and qualitatively the most important phase is an open question (Hopkins & Wallerstein, 1977; Nef, 1964). Most discussions of industrialization, however, have neglected the role of what I call *frontier industrialization*. In the Americas during the early modern period, the two most significant generators of value were silver and sugar. Both were highly industrial by any standard of the day. Not only did they require fairly heavy capital inputs, but in the case of sugar a highly rationalized labor process was necessary. The extractive and agricultural character of frontier industrialization under conditions of ceaseless capital accumulation meant that not only was ecological exhaustion a fact of life in these areas, but that ecological exhaustion was a major impetus to further capitalist expansion and to the system’s cyclical fluctuations. Ecological exhaustion at the point of

routes. Even religious missions were sites of commodity production (Monroy, 1995; Sweet, 1991).

production was complemented by an environmentally destructive multiplier effect which led to, *inter alia*, deforestation, massive soil erosion, siltation, climate change, and other effects in the case of sugar, and deforestation and the poisoning of mountain rivers in the case of silver mining (see below, and for mining, Bakewell, 1987; Dunaway, 1996b). Furthermore, by emphasizing frontier industrialization as a process coterminous with the consolidation of the capitalist world-economy over the “long” sixteenth century (1450–1640), I contend that the contemporary global ecological crisis is not rooted in the so-called Industrial Revolution *per se*, but in the logic of capital itself—with or without Satanic Mills.

THE SUGAR FRONTIER

Few commodity frontiers have contained such an expansionary and environmentally transformative logic as sugar. The production and sale of cane sugar played a central role in the development of capitalism from the fourteenth to the nineteenth century. Just how significant was the sugar complex in early modern capitalism? James Blaut makes the plausible claim that the economic significance of sugar should be placed alongside New World silver. “The sugar plantation economy was the single largest productive sector in . . . [early modern capitalism], aside from family farming, and by far the largest single generator of value” (Blaut, 1993: 198; also Furtado 1963: 71).

The sugar frontier was such an intensively transformative historical structure because sugar monoculture rapidly exhausted soil fertility through a process of highly unequal, and very rapid, ecological exchange. From this perspective, the sugar frontier was the paradigmatic case of the “metabolic rift” that characterized the change in nature-society relations once the transition to capitalism commenced. With the creation of a world market and a trans-Atlantic division of labor in the sixteenth century, the localized ecological problems of the feudal era gave way to the globalizing problem of the metabolic rift under capitalism, whereby the products of the countryside (especially but not only in the peripheries) flowed into the cities, which were under no obligation to return the waste products to the point of production. Nutrients were pumped out of one ecosystem in the periphery and transferred to another in the core. In essence, the land was progressively mined, until its relative exhaus-

tion fettered profitability, whereupon capital was forced to seek out fresh lands, the incorporation of which inaugurated a new phase of capitalist development on a world scale (Foster, 1999; Moore, 1999).

This unequal ecological exchange would become particularly apparent when eighteenth century British workers consumed sugar products even as Caribbean slaves starved, mostly because so little real food was grown on many sugar islands and food imports fluctuated according to ecological and economic cycles (Mintz, 1985; Carrington, 1987; Davis, 1973: ch. 15). Part of the task before us, in grappling with the complexities of the sugar complex's ecological transformations, is to appropriate the insights of agricultural ecology for use within an ecological world-systems framework. An agroecological historical perspective helps bring into focus the "totality of interdependent crops, animals, humans, soils, and woodlands," allowing for a deeper understanding of the interrelations between deepening market integration, spatial expansion, and ecological degradation (Merchant, 1989: 153, 149–97; Worster, 1990).

The sugar commodity frontier illustrates the fundamentally restless nature of world capitalism. Consider the long-run changes in the geography of sugar production. Capitalist sugar production developed during the late medieval period in the Mediterranean—especially on Crete and Cyprus (Solow, 1987). During the early stages of Portuguese expansion in the second half of the fifteenth century, the locus of sugar production moved to the Atlantic islands, especially Madeira (Verlinden, 1970). In the late sixteenth and early seventeenth centuries, production shifted again, to coastal Brazil. By the middle of the seventeenth century, the Caribbean, especially Barbados, became the center of world sugar production; Cuba and Jamaica became preeminent by the late eighteenth and early nineteenth century. And by the late nineteenth century, sugar production was truly globalized (Deer, 1949–50; Galloway, 1989; Mintz, 1985; see Tomich, 1990; 1991; 1994 for an exceptional world-systems account of nineteenth-century sugar production in the Caribbean). Part of this restlessness can be explained by technological innovations and changes in labor supply. The primary factor, however, was environmental transformation, which often necessitated changes in, especially, technology. The ecological dimension should never be abstracted.

Sugar production was both labor- and capital-intensive. Of special importance was the central role of sugar in creating capitalist slavery. In contrast to wheat but similar to cotton (Earle, 1988) sugar

cane required labor throughout the year, which discouraged free labor even if it could be obtained cheaply, which was rarely the case on any frontier. Sugar production was profoundly industrial, involving a degree of labor process coordination and capital intensity that was rare in the early modern world-system (Mintz, 1985). "The sugar plantation changed colonial societies in much the same fashion that the factory . . . changed English society" (Davis, 1973: 215). In large part, the industrial character of sugar production was mandated by the ecology of sugar cane, which requires that cutting, milling, and boiling occur within 48 hours; sugar cane desiccates rapidly once it is cut. As a consequence, the labor process of sugar production was highly rationalized and time-conscious. "This time consciousness was dictated by the nature of the sugar cane and its processing requirements, but it permeated all phases of plantation life" (Mintz, 1985: 51). Sugar production required both skilled and unskilled labor, providing an early glimpse of the capitalist labor process, including such dynamics as deskilling. "The specialization by skill and jobs, and the division of labor by age, gender, and condition [of labor, that is, slavery] into crews, shifts, and 'gangs,' together with the stress upon punctuality and discipline, are features associated more with industry than with agriculture—at least in the sixteenth century" (Mintz, 1985: 47).

Sugar has a very long history, but for present purposes I will start the clock on the capitalist sugar frontier in the fifteenth century with the incorporation of the Atlantic islands into the emergent capitalist world-system. The first major sugar-producing area outside the Mediterranean was the island of Madeira, settled by Portuguese colonists in the 1430's. The development of Madeiran sugar production foreshadowed much of this commodity frontier's history in the early modern period. Over a decade before settlers arrived on this uninhabited island, they had put ashore cows, pigs, and sheep. This practice would be repeated in the Azores, the Cape Verdes, and much later Barbados. Consequently, the island's ecology was transformed even before human arrival. This was not always to the settlers' advantage. The attempted settlement of nearby Porto Santo was hampered by the accidental release of rabbits on the island in the 1420's. The rabbits devoured the island's ground cover, leading to wind and rain erosion (Curtin, 1990: 75; Johnson, 1987: 3; Solow, 1987; Verlinden 1970). For the moment, Madeira's heavy forest cover protected the island from a similar fate.

Throughout the early modern period, sugar production almost always followed a stage of agrarian development based on smallholding agriculture practiced with minimal capital inputs. Most often, the first settlers engaged in the cultivation of wheat or other grains, often in combination with a cash crop such as tobacco, which required few capital inputs. In so doing, the initial settlers prepared the social as well as environmental “ground” for sugar cultivation. We might call this (settler) stage of capitalist expansion the grain *surplus* frontier rather than a commodity frontier. On the surplus frontier, settlers were not compelled to “sell to survive” by the capitalist market. Rather, they practiced a “subsistence-surplus” agriculture whose world-historical function was to organize the human and natural resources in preparation for a more intensive stage of commodity production (Moore, 1997). Sugar cultivation tended to be unsuccessful in those locations—such as Hispaniola in the sixteenth century—which had *not* been prepared by a grain surplus frontier (Mintz, 1985; Watts, 1987: 103–04). The transition from a grain surplus frontier to the sugar commodity frontier was a moment of ongoing primitive accumulation. In Madeira, this occurred under the impetus of Genoese and Flemish capital as settlers were displaced in favor of sugar plantations, whose annual output increased from about 80 tons to over 1,000 tons between 1456 and 1494 (Diffie & Winius, 1977: 306–07; Schwartz, 1985: 8).

The transition from wheat to sugar had two major consequences, which would be repeated many times over the next few centuries. First, foodstuffs had to be imported, thereby widening and deepening the world-economy’s interdependent division of labor. In the case of Madeira, wheat was shipped from the Azores; in the case of the Caribbean islands in the seventeenth and eighteenth centuries, North America and Ireland supplied food (Davis, 1973: chs. 1, 15–16; Carrington, 1987; Sheridan, 1973; Truxes, 1988). Secondly, the shift to sugar production necessitated a larger unit of production, itself a key indicator of incorporation into the world-economy.³ The

³ “It seems clear the ability to respond is a function in part of the size of the decision-making unit. A larger unit is more likely to have an impact *on itself* and its own prospects for capital accumulation by altering its production decisions in light of what it believes to be altered conditions in some market. It follows that, for enterprises in a zone to begin to respond in this way, they may have to become larger. The creation of such larger units of decision making may occur either at a site of direct production (e.g., by creating a ‘plantation’) or at a site of mercantile collection of production” (Wallerstein, 1989: 130).

increase in the size of the average sugar estate relative to that of grain and tobacco farms seems to have been a negative environmental factor in itself (Watts, 1987: 167). Hence, the island's deepening incorporation in the emergent capitalist world-system was also a moment of deepening environmental degradation.

Before any significant agriculture could begin, Madeira's heavy forest cover had to be cleared. In the timber-starved Mediterranean world of the time, timber exports were highly lucrative (Cipolla, 1976: 229–30; Özveren, 1994). But commercial cutting was slow, and settlers were starved for land. The forests were burned, and the proliferation of European animals, in addition to intensive agriculture, ensured that the island's "forests would never recover" (Crosby, 1986: 76).

Madeira's low rainfall meant that irrigation works had to be built if sugar was to be grown. Building an agroecological infrastructure capable of sustaining a sugar export sector took some time. Twenty years elapsed between the introduction of sugarcane to the island and the commencement of sugar exports in the 1450's (Galloway, 1989: 50). The construction of this infrastructure was as global as it was transformative. Technical expertise and financing were supplied by the Genoese, Portugal covered protection costs, and African slaves (imported by the Genoese and Portuguese) performed most of the labor. The labor requirements were immense, exacting a high price in human lives. According to Alfred Crosby, "much of the land was too steep for normal practices of cultivation and had to be terraced. Most back-breaking of all the tasks, and the most dangerous, was the creation of a vast and complicated irrigation system to bring water from the windy and sodden uplands to the cultivated fields far below" (1986: 78; also Watson, 1983: 103).

Under the impetus of an expanding world market for sugar, the consolidation of large landholdings thanks to Genoese financing, and sufficient labor provided by the slave trade, Madeira became the world-economy's largest sugar producer by the late fifteenth century (Galloway, 1989: ch. 4; Schwartz, 1985: 8). By the 1490's, however, the world sugar market was glutted. Overproduction coincided with increasing soil erosion, which lowered productivity. This allowed for a shift in the center of sugar production to Brazil by the second half of the sixteenth century (Duncan, 1972: 31; Galloway, 1989: 54; Novais, 1991: 24–26; Schwartz 1985: 9). The locus of production would shift again in the next century to the Caribbean islands.

The expansion of sugar cultivation went hand in hand with monocultural production, a prime example of capitalist agriculture's drive "toward the radical simplification of the natural ecological order" (Worster, 1990; also see Haila & Levins, 1992: ch. 5). Such simplification is inherently disruptive. Under conditions of generalized commodity production and the imperative of ceaseless capital accumulation, monocultures are especially unstable owing to the competitive pressures of the world market. Competition means that ecosystems which might otherwise regenerate in time are not allowed to do so. In addition to these factors, European agricultural practices, such as row-style plantation agriculture and planting sugar in trenches, exacerbated problems of soil erosion due to wind and water. Row planting would be supplanted by cane-hole agriculture only after long experience with soil erosion (Sale, 1990: 165; Watts, 1987: *passim*, esp. 402–05).

The advance of the sugar frontier to the Americas by the mid-sixteenth century marked a qualitative shift in the scale and scope of capitalist ecological degradation. One of the principal agents of this degradation was the plantation. In no small part, it was the climate of the Americas—especially the high rainfall—that made possible this form of agricultural enterprise. "The discovery that sugar could be grown well in the New World without irrigation made American cane plantations the prototype of virtually the whole development of the subsequent growth of plantations of the world" (Sauer, 1981: 49–50).

The sugar market's steady (if discontinuous) growth, it bears repeating, was the driving force behind the massive expansion of African slavery, the development of the so-called triangular trade, and the growth of transatlantic shipping in bulk goods. These trends were reinforced with the onset of sugar production and export in Brazil, where the sugar complex was the "central social institution" of colonial life during the seventeenth century (Lockhart & Schwartz, 1983: 204; Mintz, 1985: 43–46). By the 1650's, Brazil would be eclipsed by the Caribbean as the center of world sugar production. This was the period when sugar consumption became increasingly widespread in the European core. By the end of the eighteenth century a wide range of sugar products became something of a staple in English working class households (Mintz, 1985).

I will discuss the ecological effects of the sugar complex thematically rather than chronologically, in order to convey a sense of the scope of environmental transformation during this period.

First, let me summarize crudely the basic economic pressures of the sugar complex. As was (and is) so often the case in the modern world-system, the real money in sugar was made not by planters but by merchants and financiers (Blaut, 1993: 191–92; Braudel, 1982: 190–94, 272–78; Deerr, 1949–50: II, 291; Edel, 1969). As with most economic activities in the periphery, competition in the sugar sector was intense.⁴ Planters were almost always heavily indebted and membership in the planter class was highly unstable (Dunn, 1973; Lockhart & Schwartz, 1983: 207; Sheridan, 1973). Such instability reinforced the already powerful tendencies of capitalist planters to overexploit land and labor, which led to declining productivity, which drove the sugar frontier ever onwards to virgin soil, which in turn required fresh supplies of capital and labor. A vicious circle indeed! American planters were yoked to an “international debt peonage” reminiscent of early modern eastern Europe (Wallerstein, 1979: 41). Financiers, not planters, were the primary beneficiaries of the sugar frontier complex. Not coincidentally, these agents of this peonage in successive historical epochs were based in the respective centers of world finance—Genoa, Amsterdam, London.

How did European colonists approach the New World? Richard Pares (1960: 20) sums up the initial approach in terms of immense waste: “The pioneers presumed upon the inexhaustible fertility of cattle, turtles, and birds, and upon the immeasurable resources of the forests: indeed, they seem to have gone berserk in the presence of so much edible wild life and a continent covered with firewood. In time, this waste went too far” (1960: 20).

Immanuel Wallerstein has noted that sugar, like wood, was the “continuing ‘growth’ crop” of the early modern world-economy (1980: 161–62). The parallel is appropriate. Recall that Europe “was a civilization literally made of wood” (Sale, 1990: 84). European states and capitalists had access to wood fuel resources which dwarfed their contemporaries in the Middle East and China (Sale, 1990: 84–85). Forests were the lifeblood of the European core, and they were the lifeblood of the sugar complex. Not only was forest clearance a precondition of sugar cultivation, but wood was neces-

⁴ “[C]ore zones . . . have tended, by definition, to monopolize the high profit monopolies while the peripheral zones housed production processes operating within truly competitive markets and hence characterized by truly low-profit activities” (Hopkins & Wallerstein, 1996: 4).

sary for the immense fuel needs of the boiling furnaces which turned raw cane juice into semirefined sugar. Timber was needed to construct housing, sheds, and other buildings. It was needed by the metalworkers who made the furnaces, boilers, and tools needed to process the sugar cane. It was needed to construct hogsheads and other large barrels for shipment. And of course, it was needed to build the ships that transported the sugar to market.

The steady forward march of sugar cultivation destroyed forests in areas adjacent to the cane fields, of course. Sugar also consumed distant forests. It is impossible to know the extent to which the sugar frontier was responsible for the 260 million cords of wood which were cut in New England alone between 1630 and 1800 (Sale, 1990: 291). While most wood was cut for fuel, sugar's share of wood product exports was substantial. North American forests were cut for shipbuilding, construction, and fuel purposes, but these were not the only sugar-related activities which led to deforestation. Forests were cleared to prepare the land on which wheat was grown and livestock foraged, both of which were shipped in substantial amounts to the West Indies (Cronon, 1983: ch. 6; Merchant, 1989; Silver, 1990: 117–18; Williams, 1989).

The link between sugar and deforestation was evident from the very beginning of sugar cultivation in the New World. On Hispaniola, the first efforts at sugar planting began in 1505, and by the 1530's there were 34 mills (Mintz, 1985: 33–34). By the end of the sixteenth century, "the exhaustion of wood supply became a serious problem" on the island (Sauer, 1981: 352). Barbados, originally covered with "dense tropical forests," was virtually deforested in the 30 years after initial settlement in the 1630's. By the 1660's, some fifteen years after the first sugar exports, "Barbados had less woodland than most districts of England. . . . [C]olonists were complaining of a timber shortage" (Dunn, 1973: 26–27, 67). Barbados colonists even attempted to annex nearby St. Lucia "in order to gain access to a new supply of timber" (Silver, 1992: 117). In Antigua, "the early planters cleared the acacia and logwood forests that covered the interior of the island and converted it to cane fields" (Dunn, 1973: 34). Between 1690 and 1751, the forests which had once covered two-thirds of Antigua had practically vanished (Watts, 1987: 434–35). St. Kitts, Nevis, and Montserrat began to suffer from soil exhaustion shortly after the introduction of sugar monoculture in the 1750's, although the full impact would not be felt until the sugar boom of

the 1820's (Tomich, 1990: 140). In French Martinique and Guadeloupe, soil exhaustion "began to show itself seriously in the 1730's" (Davis, 1973: 253-54). In Jamaica, "the most fertile land ... was heavily forested ... and it took the colonists many long years to clear and plant these woodlands" (Dunn, 1973: 167). Earlier, on the sugar island of São Tomé off the West African coast during the sixteenth century, "so quickly was the forest cut back in the expansion of the sugar industry that by the mid-sixteenth century the entire littoral ... had been cleared of natural cover and turned into cane-fields" (Garfield, 1992: 82).

Clearing forests for sugar cultivation often meant setting fire to the forest, which did more than kill trees. Forest clearance also meant the virtual eradication of the animals who lived in the forest. On St. Kitts, feral hogs (left by earlier Spanish visitors), "native ground animals," monkeys, and turtles were subject to "total removal" (Watts, 1987: 166). On Barbados, deforestation led to the extinction of numerous species of flora and fauna, especially birds, "the scarcity of [which] ... has continued through to the present day" (Watts, 1987: 219-20). In New England, the extinction of birds resulted in a decline in the fertility of forest soils; we can assume that similar impacts were felt in the Caribbean (Merchant, 1989: 36). At the same time as the ecological bases of indigenous flora and fauna were being undermined, new species were being introduced in a classic instance of so-called "ecological imperialism" (Crosby, 1986). Today nearly two-thirds of Barbados' flora and fauna are not indigenous (Watts, 1987).

Forests were also destroyed in the numerous interimperialist conflicts of the period. During the Second Dutch War (1666-67), the French put to the torch those parts of St. Kitts controlled by the English; "at roughly the same time, French sailors burnt the whole island of St. Croix" (Watts, 1987). Cane fields, not to mention settlements and towns, were routinely burned during these conflicts (Watts, 1987: 240-58, 394). The ecological impacts of warfare, though a far cry from the literal scorched earth practices of the present day (witness the 1991 Persian Gulf War or the 1999 U.S. airwar against Serbia), remain largely unexplored during this period.

Animals, especially wild hogs, were eliminated by imperial authorities for social and political reasons. Sometimes wild hogs were simply a nuisance. For example, when Barbados was first settled in the late 1620's, the island "was almost overrun by" feral hogs, who

were systematically exterminated within a few years (Watts, 1987: 156). In other cases, imperial authorities attempted to destroy the cattle and hogs on various islands for political ends. Spanish forces “slaughtered the herds on which [the buccaneers] preyed” on St. Domingue. “The English authorities sent for buccaneers to kill the cattle [on Jamaica], in order to destroy the resources of the Spanish resistance movement” (Pares, 1960: 20).

The fuel requirements of the furnaces that boiled the cane juice were immense. “Any attempt at sugar production without a ready stockpile of forested land would not succeed no matter how favorable other environmental factors such as climate and soil” (Miller, 1997: 137). As early as the fifteenth century, sugar importers began to build refineries in northern Europe because fuel supplies were available nearby (Galloway, 1989: 36).⁵ In Brazil, firewood was second only to slaves as the largest item in the mill owner’s budget, consuming by the eighteenth century some 12–21% of operating costs (Schwartz, 1987: 93; Barros de Castro, 1977: 9). Rising fuel costs along with soil erosion contributed to a large number of plantation failures in this period, which in any event was a period of decline of Brazilian sugar exports (Edel, 1969: 42). During the seventeenth century, a large Bahian *engenho* required the full-time labor of eight slaves just to gather firewood. Each slave’s daily quota was approximately 1,600 pounds of firewood. During the harvest season, every large *engenho* in the region consumed some twelve to thirteen thousand pounds of firewood on a daily basis (Schwartz, 1985: 141). In terms of land requirements, one and a half to two acres of forest were needed to process a single acre of sugar cane. It is hardly surprising that there was “considerable deforestation” in the Bahian Reconcavo by the mid-seventeenth century (Schwartz, 1985: 302; Miller, 1997). Barbados had so exhausted native sources of fuel that by 1667 (sugar production began in earnest only in 1643–46) planters were forced to import coal from England. Barbadian planters were also importing large amounts of timber from British North America for construction purposes (Deerr, 1949–50: I, 166; Watts,

⁵ Probably more important than the proximity of fuel sources, as Galloway (1989) notes, was that refining sugar closer to market in northern European allowed merchants to avoid the risks associated with transport, during which much sugar arrived in port water-damaged. The risks involved in refining and marketing in Europe were considerably less than those associated with cultivation and transport.

1987: 173, 186, 206, 397–98). In Mexico during the sixteenth century, “the fuel needs of Spanish enterprises, particularly sugar . . . , seriously encroached upon the Indians’ supply of firewood” (Frank, 1979: 33). At the same time, in a dynamic that continues today, Spanish expropriation of the most fertile agricultural land—in part for sugar cultivation, especially around Cuernavaca—pushed indigenous peoples onto marginal forest soils, which were quickly depleted (Frank, 1979: 33–35).

Although planters eventually found an alternative source of fuel, by using *bagasse* (milled cane stalks) and employing the more efficient Jamaica train furnace—necessitated by the deforestation of Caribbean sugar islands—timber was always the first choice for fuel. Throughout the early modern period, however, *bagasse* was useless as a fuel source because the sugar mills’ crushing rollers were too light, leaving the cane stalks damp (Sauer, 1981: 352). It was only when faced with the pressures of environmental exhaustion that planters made more “efficient” use of the natural environment. Where forests were plentiful, planters preferred wood over *bagasse*. Planters in Cuba used wood as the primary fuel source in many areas until the mid-nineteenth century, in northeast Brazil until the early nineteenth century, and in Peru cane stalks were seldom used until the introduction of the “Louisiana Number 1” mill in the early 1870’s (Moreno Fragnals, 1976: 38–39; Galloway, 1989: 97–99; Knight, 1972: 29–30). Moreover, not only did the fuel requirements of the sugar sector deplete forests, but wood burning itself “resulted in the transfer of many vegetative stored nutrients away from the immediate environment [and] into the atmosphere,” thereby crippling the reproductive capacity of the local ecosystem (Watts, 1987: 166–67).

Once the forests were gone, soils became highly vulnerable to erosion from wind and rain. The sugarcane itself is fairly resilient in severe weather. The soil in which it grows is not so lucky. In seventeenth-century Barbados,

Rivers began to silt up and in some cases went completely dry, estuarine habitats were destroyed by siltation and estuarine animals disappeared; and with the loss of the dense tree cover the whole hydrology, and thus the whole climate, of the area was slowly altered, at considerable cost to both land and water species (Sale, 1990: 165).

In Barbados, erosion from nearby cane fields began to clog Bridgetown harbor in the early 1660's, after just two decades of sugar cultivation (Watts, 1987: 222). By the end of the seventeenth century, Barbadian planters "complained endlessly of declining crop yields, insect and vermin plagues, drought, barren soil, and rising costs" (Dunn, 1973: 203–04). By 1685, yields on many sugar estates had declined by as much as one-half (Watts, 1987: 397). Such exhaustion played a key role in the eighteenth-century shift of sugar production from Barbados to the larger islands of Jamaica and St. Domingue, which "had sufficient land to be able to abandon overworked sugar plantations and replant on virgin soil" (Davis, 1973: 254; also Dunn, 1973: 205; Ponting, 1991: 206).

The sugar frontier, in depleting the soil, required ever greater inputs of fertilizer and labor. The challenge of declining soil productivity was met, in part, by bringing in more animals to supply fertilizer, which led to more deforestation for pasturage, which resulted in yet more soil erosion. In sixteenth-century Brazil, the booming sugar sector provided the impetus to large-scale cattle ranching, where cattle were initially used as a power source for the sugar mills (Crosby, 1972: 90; Furtado, 1963: 58–66; Schwartz, 1973: 167–68). In mid-seventeenth-century Barbados, the cost of animal fertilizer increased to the point where smallholders who did not grow sugar began to raise livestock not as a source of meat or hides, but as a source of manure (Watts, 1987: 222–23; Batie 1991: 50). The existence of a large animal population—especially horses, the power source for many sugar mills at the time—provided a favorable disease climate. In 1655–56 "a virulent epidemic almost destroyed the horse population in Barbados" (Watts, 1987: 193). This development threw the sugar mills into crisis, and induced a shift to wind-power. We should note that the shift to wind-power was possible only because the island had been so thoroughly deforested (Watts, 1987: 193, 198).

As soil fertility declined, more labor was required—and slaves were the most costly part of the production process (Dunn, 1973: 197; Schwartz, 1987: 93). Seen from this perspective, the ecosocial dynamics of the sugar frontier provide an excellent illustration of how "capitalist production . . . only develops the techniques and the degree of combination of the social process of production by simultaneously undermining the original sources of all wealth—the soil and the worker" (Marx, 1977: 638). When the planter purchased

more slaves to compensate for declining yields, the pressures to exploit the soil and the slaves were accordingly intensified. In Brazil, as early as the 1580's, "an *engheno* expected to lose between 5 and 10 percent of its slaves" (Lockhart & Schwartz, 1983: 206). During the eighteenth century, slave imports to Brazil quadrupled over the previous century, despite stagnating sugar production (Smith, 1991: 35). During the late seventeenth century, slaves in Barbados were put to work carrying soil that had washed to the bottom of cultivated hillsides back to the cane fields (Watts, 1987: 297). Declining soil fertility also meant that "ratoon" crops, where the cane root is left in the ground to produce a second cane, produced diminishing yields. By the end of the eighteenth century in Barbados, "no planter ratooned more than one year. . . . Since ratooning . . . cost much less labour than planting new canes, we can see that in the course of years the exhaustion of the soil greatly increased the planters' labour costs" (Pares, 1960: 42). Throughout the West Indies the impact of soil exhaustion on labor costs could be seen:

Every decade it took more slaves to produce the same amount of sugar from the same acreage, or, where cultivation was advanced or output increased, it was only done at the cost of heavy additional labour. Thus, though between 1720 and 1755 the slave population and the sugar of Antigua, St. Kitts, Nevis and Montserrat both increased by 100 per cent, this was only possible because of the rapid exploitation of the former French lands on St Kitts—the output of Nevis and Montserrat remained stagnant. Between 1710 and 1773, in Barbados, the slave population rose by about 30 per cent . . . and the output of sugar went down by more than 20 per cent. In none of the colonies named can we suppose that planters were turning to other crops—they still produced sugar, but with more difficulty (Pares, 1960: 41; for the general relationship between capitalism, ecology, and labor, see Marx, 1977: 648–49; also see Moore, forthcoming).

And finally, sugar production effected climate change. Cristobal Colon, writing in the early sixteenth century, noted that "in the Canary, Madeira, and Azore Islands . . . since the removal of forests that once covered those islands, they do not have so much mist and rain as before" (quoted in Crosby, 1986: 96–97). In addition to deforestation, ecologists Yrjo Haila and Richard Levins suggest two

processes which might affect climate in sugar-producing regions. Writing about Cuba in the nineteenth century, but I think relevant to the Caribbean sugar islands in the early modern period, they observe that

The burning of sugar cane before the harvest put so much ash into the Cuban atmosphere that it provoked increased rainfall just when this was least desirable because it interfered with the transport of the cut cane to the mills. . . . [It is possible] that Cuba had a partly continental climate because the shallow, muddy waters along the north coast behave like land with respect to the sunlight. Therefore erosion can contribute to the heating of the earth (Haila & Levins, 1992: 153).

Nor were the effects of sugar production limited to the tropical areas in which sugar was grown. In 1614, for example, Amsterdam banned the “use of coal in the [sugar] refineries” because of air pollution (Braudel, 1982: 193). In New England, forest clearance, which resulted partly from the demands of sugar-linked shipbuilding, significantly altered the regional climate by the end of the eighteenth century. Among other things, deforestation contributed to the increased frequency of flooding and forest fires, the drying out of soils which made seasonal fluctuations more severe, and reduced stream flows (Merchant, 1989: 236; Cronon, 1983: 122–26).

Just as the sugar complex enslaved workers and degraded the land, so it enslaved (peripheral) regions by deepening their dependency on the core. Peripheralization was about unequal *ecological exchange* as much as it was about surplus extraction. Marx’s comment on the relationship between Ireland and England in the eighteenth century applies equally well to the relationship between Barbados and England in the early modern period: “Ireland is at present merely an agricultural district of England which happens to be divided by a wide stretch of water” (1977: 860). Sidney Mintz perceptively notes that the expansion of sugar production and the growth of slavery in the British West Indies took place at the same moment as England was experiencing the formation of an industrial wage-labor proletariat (1986: 43–44; also 1978). This is precisely the world-historical process Marx commented upon in the first volume of *Capital*: “the veiled slavery of the wage-labourers in Europe needed the unqualified slavery of the New World as its pedestal” (1977: 925).

A world-historical ecology of the sugar complex—one that would study the interconnections between deforestation and soil erosion in the New World, air pollution caused by sugar-refining plants in core areas such as Amsterdam, the impact of increased sugar consumption on the health of consumers and the formation of an industrial proletariat, the role of sugar as a source of cheap calories for workers in core zones such as England, the ecological degradation resulting from the massive importation and breeding of livestock in the New World, the human ecology of slavery and workplace health and safety, and many other elements of a world-systemic dialectic of ecosocial change—remains to be written. I have tried to draw out in broad strokes some of the most conspicuous dimensions of the sugar complex's ecological transformations and to link these transformations with capital's imperative of ceaseless geographical expansion.

CONCLUSION

The sugar commodity frontier was a vanguard sector of early modern capitalist spatial expansion for two main reasons. First, the steady growth of the world sugar market throughout the early modern period meant that existing land under cultivation was over-exploited and that new lands were always needed, partly to replace worn-out lands, partly to expand production. Secondly, and in some ways more significantly, the sugar frontier set into motion a vast complex of economic activities, from slave-trading to cattle-ranching to shipbuilding to foodstuff agriculture. Particularly important are the ways in which the sugar frontier called forth a complex of commodity frontiers in the Americas, leading simultaneously to market-widening and market-deepening. In North America, for instance, the Caribbean sugar complex pushed forward a timber frontier to feed a growing shipbuilding industry and to export timber to the sugar islands for construction and other purposes; it fueled a cattle-ranching frontier in the southern states; and it facilitated the emergence of export-oriented wheat agriculture in the Virginia and Maryland colonies, to name but a few examples.

The defining ecological feature of capitalist agriculture is “the radical simplification of the natural ecological order” (Worster,

1990: 1101).⁶ In any one place, such radical simplification is unsustainable over the medium run of 50 to 75 years. Either overexploitation leads to exhaustion, or simplification renders crops vulnerable to disease, both leading to falling productivity and profitability. As Karl Polanyi (1957) argued some fifty years ago, capital's inner logic is to commodify the land and labor that provides the foundation for continued accumulation, thereby undermining the human and natural foundations of the system. Sugar illustrates this dynamic. Depending on supplies of uncommodified land, sugar planters under capitalist market pressures were forced to commodify and as a consequence to degrade the land, thus setting the stage for further expansion. The complex of primary product commodity frontiers in the Americas, often originating in response to sugar and sometimes silver were caught up in the same, if sometimes less conspicuous, dynamics.

The concept of the commodity frontier should be situated within a broader typology of capitalist spatial expansion. The capitalist world-economy is inherently expansionary. Ceaseless spatial expansion is the product of a system based on ceaseless capital accumulation. During the early modern period, there were two modalities of spatial expansion: one largely redistributive and trade-based; the other essentially transformative, based on the organization of commodity production. The first mode of spatial expansion was that of a "trading post" imperialism, which operated in Africa and Asia (Curtin, 1984; Pearson, 1987).

The second mode of spatial expansion I call the frontier mode. The frontier mode of expansion, the primary arena of which was the Americas, was distinctive because it was ecologically and sociologically transformative to a degree impossible elsewhere in the world, even in most of Europe. In the Americas, capitalists and their state agencies had a kind of "clean slate" advantage. The forces that limited expansion elsewhere were not so important in the New World, and it was here that social transformations such as industrialization could be seen first in some of their most advanced forms. The frontier mode was not the child of capitalism but a condition of its birth and consolidation. "The Americas were not incorporated into

⁶ I am aware that Worster's invocation of "the natural ecological order" is problematic. However, to plunge into that debate would lead us too far afield.

an already existing capitalist world-economy. There could not have been a capitalist world-economy without the Americas" (Quijano & Wallerstein, 1992: 549). In short, without the Americas there was no capitalism; without capitalism, there were no Americas.

The case of the sugar commodity frontier serves to clarify and specify the ways that capitalist specialization, under conditions of increasingly generalized commodity production and the imperative of ceaseless capital accumulation, destabilizes local ecosystems. Local ecosystems which might otherwise have regenerated in time were not allowed to do so. Destabilization in turn led to falling productivity and profitability and thence the renewed search for fresh land, often found outside the existing boundaries of the capitalist world-economy.

The sugar frontier was a fundamental moment of the transition to capitalism during the "long" sixteenth century. It was the classic instance of capitalism's "metabolic rift," whereby the nutrient cycling between town and country is progressively disrupted, leading to ecological exhaustion in the countryside and worsening "pollution" in the cities. All complex historical systems to some degree have been afflicted by a metabolic rift. But it is capitalism that has widened this rift as never before, as part and parcel of the historically unprecedented polarization between core and periphery.

As the case of the sugar frontier suggests, the significance of the metabolic rift in the history of the world-economy's geographical expansion can hardly be overstated. The opening of the world-scale metabolic rift in the sixteenth century meant that capital could not survive as a "closed cycle system," to borrow a phrase from ecology. Whereas closed cycle systems "continuously recycle their own nutrients," capitalism is a "flow system" that is "depend[ent] upon an external nutrient supply that ... [it] cannot ... produce" (Fischer-Kowalski & Haberl, 1993: 416). Capitalism's dependence on external resources rises over time, as it requires ever larger energy inputs in order to reproduce itself. As a result, the system experiences a geometrically increasing "energy density"⁷ that today is fast approaching natural limits, as capital hogs an ever-larger share of the world's energy for itself, leaving an ever-smaller share for the

⁷ "Energy density means the amount of energy taken in and being transformed by the system per calculation unit (space or organism)" (Fischer-Kowalski & Haberl, 1993: 416).

planet's other (nonhuman) residents (Fischer-Kowalski & Haberl, 1993: 416–17). As long as capitalism did not encompass the entire globe, these natural limits could be overcome by geographical expansion and to a lesser extent by a shift to capital-intensive agriculture, although the possibility of the latter ultimately depended on the success of the latter.

From this perspective, Rosa Luxemburg's insights on the indispensable function of the "non-capitalist environment" (1970: 417) for capital accumulation, and the former's gradual penetration and destruction by capital and imperial states, can be applied to the historical relation between capital and nature.⁸ "The accumulation of capital is a kind of *metabolism* between capitalist economy and those pre-capitalist methods of production without which it cannot go on and which, in this light, it corrodes and assimilates" (Luxemburg, 1970: 416, emphasis added). The same argument that Luxemburg applied to noncapitalist social organizations can be applied to ecosystems hitherto beyond the direct reach of capital. In this way, the imperative of capitalist spatial expansion—one of the few imperatives actually grasped by contemporaries in the early modern era (Hopkins & Wallerstein, 1977)—can be seen to contain a profoundly ecological dimension. Indeed, as this study of the sugar frontier suggests, ecological degradation may be said to have been *the* primary force behind the cyclical geographical expansion of the world-econ-

⁸ Like Marx, Luxemburg did not face directly the issue of formidable ecological barriers to expanded accumulation. Nevertheless, consider her observation on the importance of natural resources:

Thus, if [the advanced capitalist nations] were dependent exclusively on elements of production obtainable with such narrow limits, its present level and indeed its development in general would have been impossible. From the very beginning, the forms and laws of capitalist production aim to comprise the entire globe as a store of productive forces. Capital, impelled to appropriate productive forces for purposes of exploitation, ransacks the whole globe, it procures its means of production from all corners of the earth, seizing them, if necessary by force, from all levels of civilization and from all forms of society. The problem of the material elements of capitalist accumulation, far from being solved by the material form of the surplus value that has been produced, takes on quite a different aspect. It becomes necessary for capital progressively to dispose ever more fully of the whole globe, to acquire an unlimited choice of means of production, with regard to both quality and quantity, so as to find productive employment for the surplus value it has realised. . . . The process of accumulation, elastic and spasmodic as it is, requires inevitably free access to ever new areas of raw materials in case of need, both when imports from old sources fail or when social demand suddenly increases (Luxemburg, 1970: 358).

omy from the fifteenth to the nineteenth century, when the entire globe was finally drawn into capital's orbit. Having reached its global limits, the implications for the future of the capitalist world-system are only all too clear.

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