# *Madeira, Sugar, and the Conquest of Nature in the "First" Sixteenth Century*

## Part I: From "Island of Timber" to Sugar Revolution, 1420–1506

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> In the long march toward the modern world-system, *mass* commodities—gold, sugar, slaves, cotton, coal, oil—have been its beasts of burden. They have sometimes served as markers for entire historical epochs.... They are the motors of production, the ultimate hard currency of exchange (Retort, 2005: 39).

Madeira is a small island with a large place in the origins of the modern world. Lying some 560 kilometers west of North Africa, Madeira was home to the modern world's first cash crop boom, a sugar revolution. In the second half of the fifteenth century, the Portuguese Crown, Italian and Flemish capitalists, and Canarian and African slaves converged on this modest island to organize a commodity revolution that would catapult Madeira to the commanding heights of the European sugar economy. Cyprus had never produced more than 800 tons of sugar, and this figure had taken centuries to achieve; from almost nothing at mid-century, by 1500 Madeira outproduced its closest competitor by a factor of 6:1 (Maddison, 2001: 58). Madeira's decline was no less rapid. The island's sugar production peaked in the first decade of the sixteenth century; by 1530 output had fallen by 90%. The furious pace of transformation, on both sides of the peak, can hardly be overemphasized. It is this, more than anything else, which distinguishes Madeira from its medieval forerunners.

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In what follows, the first of two successive articles in this journal, I explain how this epoch-making acceleration of boom and bust on Madeira, during Braudel's (1953) "first" sixteenth century (c. 1450–1557), marked a new crystallization of the nature-society relations pivotal to the rise of capitalism. The endless accumulation of capital, in this reading, is the endless conquest of nature. The very conditions of Madeira's rapid ascent were the conditions of its rapid decline. These stemmed from the rapid organization, and consequent exhaustion, of the relations governing human and extra-human nature: labor and land. These relations allowed for the rapid advance of sugar at the expense of the forest; in time, deforestation undermined the sugar regime's capacity to reproduce itself.

This first sugar revolution was local but not local*ized*. It was constituted by new flows of capital, power, and nature whose convergence marked an epochal shift in human history. The intention is, therefore, only partly one of excavating the "environmental history *of*" Portuguese colonialism and seaborne expansion. A more fundamental task is posed by what I call "environmental history *as*." Here, the challenge is to reveal Portuguese expansion *as* environmental history, *as* a socio-ecological project and process aimed at establishing new rules of reproduction for the relations of humans and the rest of nature. In the first article (Part I of this essay), I examine the conditions and transformations of Madeira's sugar revolution. I show how the rapid appropriation of biophysical wealth was vital to the sugar boom, and that the apex of this boom (c. 1490–1510) reveals the historical limits of this expansion. This analysis sets the stage for my account, in the second article (Part II of this essay), of Madeira's crisis—manifested in a 90% contraction of sugar production between 1506 and 1530.

## SUGAR IN THE CAPITALIST WORLD-ECOLOGY: THEORETICAL FRAMES

Sugar, we know quite well by now, was wrapped up in the making of early capitalism, pivotal in the formation of the slave trade, precociously industrial in its agro-ecological organization, important as a source of investment capital for the Industrial Revolution, dynamic in its interweaving of production and consumption

relations in everyday life (Mintz, 1985; Blackburn, 1997; Galloway, 1989; Schwartz, 2004; Sheridan, 1973; Tomich, 1990). But just what, pray tell, does the history of sugar tell us about historical capitalism as world-ecological process and project?

Sugar revolutions in the long transition to capitalism issued two relentless facts. One was about human nature as labor power; another was about extra-human nature as resource. The first, and best recognized, is the intimate connection between sugar, slavery, and the plantation. No history of modern slavery is complete without sugar, and no world-historical reckoning of sugar can escape the pivotal role of Madeira—even if historians of sugar and slavery find little agreement on just how *modern* Madeira really was (Greenfield, 1977; 1979; Verlinden, 1970; Solow, 1987; Curtin, 1990; Galloway, 1989; Mintz, 1985; Vieira, 2004).

Our second fact turns on the contradictions inscribed in the endless commodification of global nature. Amongst environmental historians, Madeira's claim to fame rests on the island's deforestation (Crosby, 1986; Perlin, 1989; Williams, 2003; Grove, 1995; 2002; Moore, 2000b), for these scholars the surest sign that a new mode of producing nature had arrived. The modern story of sugar is the story of capitalism's inexhaustible appetite for human and extra-human nature in servitude to the commodity form. To speak of sugar as "mass commodity" (Retort, 2005: 39) is to highlight its production of nature, its capacity to extract as much as possible, as quickly as possible, from local environments—and then, to move on. To say that sugar was a mass commodity is to say, in other words, that sugar was also a commodity *frontier* that capitalism developed *through* the socio-ecological crises that attended every sugar complex, *not in spite of them*.

Madeira is, in other words, bound up with two great historiographical and theoretical debates, one turning on the transition to capitalism, the other, on the origins of today's socio-ecological crises. The two debates reflect a singular historical process: the rise of capitalism as a profound rupture with pre-modern patterns of nature-society relations (Moore, 2000a; 2000b; 2003a; 2003b; 2007). It is my intention to move beyond the grafting of social and economic history onto environmental history, and vice versa (e.g., Taylor, 1996), in favor a synthesis premised on the production of nature, the accumulation of capital, and the pursuit of power as differentiated moments within a singular world-historical process.

That process I take to be the modern world-system (Wallerstein, 1974), which is, in my view, a capitalist *world-ecology* (Moore, 2003c; 2007; 2008; 2010a; 2010b; 2010c; forthcoming a; forthcoming b). In world-ecological perspective, historical capitalism does not *act upon* nature so much as *emerge and develop through* the dialectic of human and extra-human nature. Far from a social force that imposes its terrible "footprints" upon a passive and external nature, the world-ecological perspective offers a different way of seeing, viewing capitalism as a symbolic and material matrix, co-created through the activities of humans with the rest of nature. The term I use to capture this relation—so often misstated as the nature-society dialectic, as if the categories themselves were somehow formed independently of one another—is *ecology*. But where "ecology" is often deployed interchangeably with "environment" and "nature," I draw inspiration from the Greek philosopher and botanist Theophrastus' rendering of *oikeios*, to refer to the *relation* between a plant species and its environment (Hughes, 1994: 4). The (so-called) dialectic of "nature" and "society" are the *results* of this relation, the *oikeios*, not its point of departure (Moore, forthcoming a). Capitalism, from this standpoint, does not *have* an ecological regime. It *is* an ecological regime—a complex, contradictory, and utterly messy bundle of human and extra-human natures.

I have indicated that Madeira's place in the modern world-system is typically approached from one of two perspectives. The perspective of social history focuses on sugar and slavery (Verlinden, 1970; Curtin, 1990; Galloway, 1989; Greenfield 1977; 1979; Solow, 1987; Vieira, 1995; 1996; 2004). The perspective of environmental history focuses on landscape changes (Crosby, 1986; Grove, 1995; 2002; Perlin, 1989; Williams, 2003). Ontologically, these two ways of writing history flow from a singular way of seeing the world. In this Cartesian optic, human nature, the stuff of class struggles and world markets and imperialisms, goes into one box; extra-human nature, the stuff of forests and soil and rivers, goes into another. The agencies within each box interact, but their relations do not change the boxes themselves. In other words, for social and environmental historians both, the relations between these two historical moments are consequential, *but they are not constitutive*. For instance, no one has yet argued for a reconceptualization of modern slavery *as* a socio-ecological process. The difficulty with the Cartesian binary is that it obscures the really decisive bundles of

relations. On the one hand, the social historians study the origins of the plantation complex, with little concern for its biophysical consequences (e.g., Curtin, 1990). On the other hand, the environmental historians examine the landscape changes issuing from European colonialism and the sugar frontier, but with little analysis of the relations of power and production inscribed in the latter (e.g., Galloway, 1989). Is there not an opportunity here, to see the rise of the plantation complex—indeed the rise of capitalism—as a socio-ecological project?

How then might we rework Madeira's sugar cycle as constitutive—and not simply derivative—of the rise of capitalism as world-ecology? The approach on offer views the political ecology of the island's successive cash crops—timber and cereals, then sugar and wine—as irreducibly multilayered. These commodity regimes were, to be sure, instantiations of the political ecology of Portuguese empire, and of an emergent capitalism. And yet, to emphasize the many scales of modern environmental history is a far cry from writing top-down history. World-systemic and world-scale processes are analytically distinct; indeed a central premise of the world-historical perspective is that transformations of the body, of the labor process, of households, of cities, regions, and states are *all* constitutive of historical capitalism.[1] Madeira's sugar revolution was no global derivation. Its socio-ecological transformations took shape out of the manifold contradictions of the late medieval crisis (see Moore, 2007: ch. 1), and Madeira's transformation in turn shaped the conditions and contours of imperial power and capital accumulation—above all, Portugal's "urgent imperialism" (Pereira, 2006) and the initial formation of the capitalist Atlantic in the first sixteenth century. It was an ongoing movement. Madeira's sugar revolution may have been a one-time affair, but it was not merely the product of one-time conquest and plunder; it was made possible, and then sustained, by an empire and a world-ecology for whom commodity-centered expansion was not simply a way of life, but an existential condition.

[1] The most sophisticated approach that embodies this multi-scalar sensibility is Tomich's classic study of sugar and slavery in Martinique (1990; see also Moore, 2002; 2003b).

## THE "ISLAND OF TIMBER": MADEIRA AND THE FATE OF THE FOREST

In the rise of capitalism, sooner or later everything returned to the forest. Every decisive commodity sector in early capitalism—metallurgy, sugar cultivating, shipbuilding, construction—found its lifeblood in the forest. Even cereal cultivation—one thinks of Polish grain flowing to seventeenth century Amsterdam—was bound up with forest clearance on a grand scale (Moore, 2010b). And so it is hardly coincidence that the Portuguese name for the island, "*ilha da Madeira*," translates literally as "island of timber" (Cadamosto, 1937 [1455]: 8). When the first settlers arrived in the 1420's, the Venetian traveler Alvise da Ca' da Mosto (Cadamosto) reports, "there was not a foot of ground that was not entirely covered with great trees" (Cadamosto, 1455: 9). By the 1560's, when the great poet-adventurer Luis de Camões visited the island, he remarked that Madeira, once famed for its sylvan bounty, had long since become an island of timber in name only (Camões, 1996 [1571]: 296).[2]

What happened between the 1420's and the 1560's? In a word, capitalism.

When one encounters the history of Madeira, amongst the first things one learns is the island's origin myth. Like all such myths, it is about nature. The first settlers, confronting an impossibly dense sylvan landscape, set fire to the forest. Cadamosto's is only the most frequently-cited account. "So great was the first conflagration," he tells us, that the first settlers were forced "to flee its fury and take refuge in the sea, where they remained, up to their necks in water... for two days and two nights. By this means they razed the great part of this forest, and cleared the ground for cultivation" (Cadamosto, 1967 [1455]: 9). The fire "took such possession, that it burnt seven years continually, and was seen far off in Smoak and Sparks like *Mount Aetna*; so that afterwards the Island be-

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[2] "We passed the great Island of Madeira,
Called such for its many stands of trees,
[the site] that we first peopled,
[now] more famous for its name than for its glory" (Camões, 1571: 296).

Even earlier, during the 1530's, the timber situation on Madeira was such that João de Barros, in the first volume of *Decadas da Asia*, observed timber scarcity on the island more than two decades before Camões penned his wry comment on Madeira's deforestation (cited in Prestage, 1933: 39).

ing plentiful of Grain, the greatest want the Inhabitants suffered was of Wood, there having been nothing else in it before" (Faria e Sousa, 1695: 4–5).

There was, in other words, a baptismal fire. Like all baptisms, its symbolic power rested in the cleansing of sin, washing away the human hand in the destruction of the island's forests. The fire had escaped human control, and prepared the island, first for the cultivation of cereals, then sugar, then wine. The enduring social power of this origin tale stems from its explanation of the rapid deforestation that did occur during the first century of settlement, and from its explanation of the timber scarcity that beset the island for centuries to come. It was an explanation that enjoyed significant traction—especially amongst English travelers—not least because it located the causes of environmental change in an accident of colonization rather than its systematic (and systemic?) consequence. Thus Samuel Purchas in the 1620's writes that "[i]n the yeere 1420 began that Plantation [Madeira's settlement], and the thicke Trees being . . . set on fire, continued burning seven yeeres: *which destruction of Wood hath caused since as great want*" (1625: 6, emphasis added). More than two centuries later, J. A. Mason took the same view, noting that "the colony sustained much inconvenience from the want of timber" after the fifteenth century as a result (1850: 156). Madeira's deforestation was, in other words, registered not only in the physical landscape; it was also inscribed in the collective memory of how this landscape was formed.

This origin myth speaks to two salient facts. First, Madeira was indeed deforested rather quickly. Madeira's sugarmills pushed back the forest at unprecedented speed after 1450. By 1510, 160 $km^2$ of forest, nearly one-quarter of the island and over half its accessible forest, had been cleared. Our second fact is implied by the first. Once the island's sugar complex had collapsed definitively, in the 1530's, Madeira *did* experience "great want" when it came to timber. It was no accident that even timber for the casks of Madeira's famed wine was shipped from New England in later centuries (Duncan, 1972: 124, 153–55; Lyall, 1827: 361).

If the modern conquest of the Atlantic was destined to be a grand affair, it began with a few modest steps. When the Portuguese occupied Madeira, a small island 740 kilometers square, in the 1420's, there was little intimation of what was to come. First timber, then grain, would flow from this Atlantic outpost toward

a metropolitan Portugal desperately short of both. It was an essentially medieval relation, perhaps not so different from Rome's tributary exactions a thousand years earlier. By the 1450's, this had changed. As Europe emerged from the socio-ecological crises of the "long" fourteenth century (Moore, 2003a; 2007: ch. 1), commodity production, long-distance trade, technological innovation, and colonial expansion revived, all in ways that looked increasingly different from medieval antecedents. As never before, the commodity form moved to center stage.

Nowhere was this "new look" more apparent than on the island of Madeira after 1450. Exporting relatively little in 1452, Madeira emerged as Europe's leading producer by the 1490's, displacing Sicily, and above all, Cyprus. Developing within the protective carapace of Portugal's "monarchical capitalism" (Dias, 1967), Madeira's sugar boom was cosmopolitan from its inception: Genoese and Flemish capitalists sustained the commerce (and soon, the production) of sugar, Portuguese settlers planted cane and drew timber from the hills, Canarian, and later African, slaves carved irrigation channels from the mountainsides, then carried out the grueling labor of planting and cutting cane.

This first sugar revolution was an audacious act of biophysical transformation. Madeira's sylvan landscape quickly gave way to savannas, its ashes feeding the soil, its trees fueling the great boilers that turned cane juice into crystal sugar. Such conquest was, in successive turns, self-sustaining and self-defeating, the source of the island's boom, and in time, the pivot of its collapse. More than 10,000 hectares were planted in sugar at the dawn of the sixteenth century, and for a few years, more than 500 hectares of forest were picked clean to feed the sugarmills, *every year.*

Medieval sugar producers had taken a toll on the forests of the Mediterranean (Lombard, 1959). But it was never like this. In medieval Europe, deforestation was measured in centuries; after 1450, in decades. From the Saxon Erzgebirge, with its silver and copper mines, to the timber districts of Stavanger, to the cereal zones on the banks of the Vistula, early modern capitalism practiced serialized deforestation (Moore, 2007a; 2010a; 2010b; Williams, 2003)—half-century booms in which commodity production surged and the forest retreated were the norm, followed by the inevitable crash. Madeira's sugar revolution—along with central Europe's metallurgical boom—would establish this pattern.

Booming by the 1470's (nurturing, incidentally, a young Cristobal Colon), Madeira's sugar economy had collapsed by the 1520's. In 1472, the island exported 280 tons, peaking at nearly 2,500 tons in 1506. By 1530, output had fallen nearly 90%, very close to its 1472 output. Madeira was not, in the main, outcompeted. Although its decline may have been reinforced by the subsequent emergence of new competitors, Madeira's sugar complex had already collapsed. Nor was this collapse the expression of a glutted market. Rather, it appears that Madeira's sugar complex collapsed under the weight of its socio-ecological contradictions, above all the exhaustion of the forests from which flowed the extraordinary fuel supplies demanded by the mills. New production centers would soon come to the fore, São Tomé by the 1540's, Pernambuco by the 1570's, Bahia in the 1620's, Barbados by the 1670's, and thence Jamaica and St. Domingue over the course of the eighteenth century (see table 1).

**Table 1**
The Sugar Commodity Frontier, 1450–1800

| Region | World Primacy |
|---|---|
| Cyprus | 1350's–1470's |
| Madeira | 1480's–1520's |
| São Tomé | 1540's–1570's |
| Pernambuco | 1570's–1620's |
| Bahia | 1620's–1670's |
| Barbados | 1670's–1720's |
| Jamaica & St. Domingue | 1720's–1790's/1820's |

Sources: Dunn (1972); Galloway (1989); Klein (1999); Maddison (2001); Mauro (1983); Moore (2007); Schwartz (1985); Pereira (1969d); Fraginals (1976); Tomich (1990).

Madeira's spectacular history begins with a deceptively simple act of Crosby's ecological imperialism (1986). Over a decade before Portuguese settlers arrived on an uninhabited Madeira in the 1420's, they put ashore cows, pigs, and sheep—a strategy of "biological invasion" (McNeill, 2003) that would be repeated across the great arc of sugar's Atlantic archipelago. Madeira's biota was

consequently transformed even before human arrival. This was not always to the settlers' advantage. Nearby Porto Santo—which along with Madeira and the Desertas constitutes the Madeira island group—had been the scene of an initial biological invasion a century before. Amongst the Eurasian animals deposited on Porto Santo were rabbits. The latter's renowned fertility and appetite for vegetation set the stage for severe wind and rain erosion by the 1430's—"to such an extent that agriculture on the island suffered seriously" (Goodfriend et al, 1994: 311). Shades of nineteenth century Australia, to be sure (Ponting, 1991: 171)!

Madeira's heavy forest cover protected the island from a similar fate. Even today, in the mountains that transect the island east to west, there survive between 15,000 and 22,000 hectares of the original laurisilva forest. The forest remains so dense that it is "almost impenetrable," except for the irrigation canals know as *levadas*, and a few paths no more than 1-2 meters wide (UNESCO, 2000: 93, 96 [quotation]; n.a., 1999).

How much difference a century would make. By the time of Camões' visit in the 1560's, the once-bountiful forests below 300 meters had been cleared. Madeira had, in the intervening century, moved from sugar to wine. It was a shift from a fuel-maximizing, to a fuel-minimizing, cash crop—not, as we shall see, by accident.[3]

The rise of sugar and the fate of the forest were closely connected at multiple turns. There were three basic requirements for sugar production in this era. There had to be labor power to cultivate and then process the cane. There had to be fuel for the boilers that cooked the cane juice. And there had to be plentiful land to ensure soil fertility, and to ensure a profitable scale efficiency, since cane milling and initial processing required heavy capital outlays.

The clearance of the land came first. Between the 1430's and the 1450's, Madeira's economy pivoted on cereals and timber. Indeed the two were of a piece. Timbering made room for cereals, and peasant cultivators found by-employment in the timber trade. Indeed, here as in so many cases, the timber frontier arrived first. São Tomé and Brazil would also begin as timber colonies (Dean, 1995; Lebigre, 2003).

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[3] With a different sequence of crops, Genoa (from which sprang the capital that powered Madeira's sugar revolution) had done much the same in its hinterland during the fifteenth century in response to serious deforestation (Lopez, 1964: 454).

The forests were not merely burned away. Timber was an important cash crop in its own right. Madeira's forests supplied the raw materials for construction, furniture, cases, and barrels for the sugar trade, and for shipbuilding, among other uses. So long as accessible forests remained abundant on Madeira, as they did through much of the fifteenth century, cheap timber drove down the costs of production on the island, and in Portugal's leading cities. Cheap construction timber meant lower costs for building warehouses, docks, and all manner of basic infrastructure in an imperial economy that drew its lifeblood from seaborne trade. Lower costs in turn enhanced Madeira's competitive position in the world sugar market, and Portugal's competitive position in the struggle for commercial hegemony in the Indian Ocean.

Madeira's timber alleviated *aggregate* pressure on Portugal's relatively sparse forests at a time when the opportunities (and imperatives) for colonial expansion were greatest (Boxer, 1969). So great were Madeira's timber exports, that the chronicler Azurara[4] reported in 1446 on its connection with a new architectural style (1453b: 300). There began to appear in Lisbon "lofty houses towering to the sky, which have been and are being built with wood from" Madeira (Azurara, 1453a: 9). So plentiful was the timber, especially its prized cedars and red yews—trees that were subsequently wiped off the face of the island (Mason, 1850)—that Cadamosto reports new styles of furniture manufactured from these valued trees (1455: 9).

We will return to the forests momentarily. It is clear that Portugal, on its own, lacked sufficient timber for its overseas ambitions (Devy-Vareta, 1985; 1986). It is equally clear that Madeira was the first major step forward in the Empire's ecological fix strategy, aimed at resolving the sylvan inadequacies of the metropolis. This would be a long march of many steps. The colonization of Madeira, from this standpoint, surely killed no less than two birds with one stone. The establishment of the island as a cereal and timber colony went hand-in-hand. Indeed, these were complementary activities.[5]

For Portugal was short of bread and not just timber (Braudel, 1972: 196–97; Malowist, 1964; Serrão, 1954). Hungry Portugal de-

[4] Gomes Eannes de Azurara (1410–74), the Crown's chief archivist from 1454.

[5] In mid-sixteenth-century Brazil, the *engenhos* during slack periods (of which there were many more in cereal than in sugar cultivation) would set the slaves to work collecting brazilwood (Mauro, 1983).

manded cereals, and the sooner the better. Settlers were shipping wheat to Lisbon by the 1430's, and more than half the harvest was exported by mid-century (Serrão, 1954; Moran, 1982: 64). By mid-century, "in the western part of the island, standing in the farm of João Gonçalves . . . the harvests [of wheat and vines] stretched as far as the eye could see" (Serrão, 1954: 339). The ash from the burned forest was worked into the soil and provided an important, albeit ephemeral, source of fertility. Once these nutrients were absorbed, yields declined, and there was renewed pressure to carve out fresh land from the forest. Cadamosto in 1455 observed that cereal agriculture, which "at first [in the 1430's] yielded a return of sixty and seventy for one, . . . at the moment . . . has declined to thirty or forty for one, *because the land is being daily exhausted*" (1455: 9, emphasis added; also Astley, 1745: 560).

This cereal-timber frontier set the stage for the sugar revolution of the 1450's in two major respects. First, in establishing a modest demographic basis for the island—there were, Cadamosto reports (1455), 800 residents in the 1450's—the cereal-timber frontier developed a smallholder society capable of growing sugar, although not without foreign capital, as we shall see. Secondly, the cereal-timber frontier coordinated the construction of the island's irrigation infrastructure. Sugar is a thirsty crop, and although the southern part of the island enjoys a mildly warm and humid climate, it would be a stretch to call it tropical. Madeira is not São Tomé or northeastern Brazil, and in contrast to these later frontiers, its sugar revolution required a significant hydraulic infrastructure. Madeira's mountainous topography is such that freshwater sufficient for large-scale agriculture could be wrested from the island only with great effort. The first irrigation canals, called *levadas*, were built in the 1430's and 1440's. From the southern half of the island, the topography rises such that one reaches an elevation of nearly 900 meters in just five kilometers, and another 1800 meters over the next 10 kilometers (see map in Greenfield, 1977: 538). It was this "unlikely relief of the island" that made the *levadas* a "gigantic undertaking" (Lamas, 1956: 104, quoted in Greenfield, 1977: 541). Today the *levadas* remain the island's most distinctive geographical feature, extending 2100 kilometers on an island that runs just 50 kilometers east-to-west and covers 741 km$^2$ (Reynolds, 1997).

It is possible that burning and timbering reduced forest cover enough to alter the island's hydrology (Grove, 1995: 29; 2002: 51). In the fifteenth century, the Socorridos River was deep enough to float timber to the shoreline, and also to power the most productive sugarmills. By the nineteenth century, it was but a "mere stream" (Mason, 1850: 162; Brown, 1901: 133; Scherzer, 1861: 64; Vieira, 1993: 6).

More certain is that rising agricultural output and growing population—augmented by Portuguese voyages to the Canaries and to West Africa—required more and more water. The ensuing construction of the *levadas* was as global as it was transformative. Technical expertise and financing were supplied by the Genoese; Portugal provided settlers, and slaves—at first Canarian and then African—performed most of the labor. The Canarians had been dragooned by successive Portuguese invasions—there were four major expeditions alongside "numerous trips" to the Canaries between 1424 and 1446 (Vieira, 1996; Mercer, 1980: 225–27).[6] Set to work building the *levadas*, the slaves were lowered and then suspended by ropes "over the mountain precipices" to carve the watercourses "out of the solid face of the rock" (Ramsey, 1920). This was dangerous work. Building *levadas* consumed human nature at a ferocious pace. "The water had to be diverted, almost always at distant points of difficult access. The task therefore *was not only exhausting but dangerous, taking many lives and was not completed for many years*" (Lamas, 1956: 104, emphasis added, quoted in Greenfield, 1977: 541). Hundreds "perished by crashing onto the rocks below" (Ramsey, 1920; also Crosby, 1986: 78; Watson, 1983: 103).

Wheat would be displaced by sugar in the 1450's. "This isle is very scarce of oile and of corne," Africanus reported in the 1520's (1600: 56). The very rapidity of this transition from grain to sugar cannot, however, be explained by market forces alone; it must be viewed in terms of the broader ensemble of Portuguese imperialism as ecological project. Sugar, it is true, was more profitable than wheat at the onset of the mid-fifteenth century expansion; but its profitability *for Madeira* and within the Portuguese Empire was conditioned on a broader geographical reconfiguration. Madeira's cereal cultivation was not simply displaced by an abstract Smithian logic. Wheat was displaced *because* it could be relocated

[6] "From the middle of the fifteenth century, the references to Canarian slaves in Madeira as shepherds and mill workers are frequent" (Vieira, 1996).

to the Azores, which became "the granary of Lisbon and Madeira" (Mauro, 1983: 206; Serrão, 1954).[7] The transition to sugar depended also on cheap labor, drawn initially from the Canary Islands and thence West Africa (Vieira, 1996; Mercer, 1980). All of which is to say that the restructuring of Madeira's political ecology was dialectically bound to the geographical expansion of the "vast but weak" capitalist world-ecology, and therefore to broader shifts in its division of labor. These movements of expansion and restructuring were decisive in establishing the conditions for the island's sugar revolution.

## CLASS/CAPITAL/PROPERTY IN THE "VAST BUT WEAK" CAPITALIST WORLD-ECOLOGY: THE CONDITIONS OF MADEIRA'S SUGAR REVOLUTION

Madeira's sugar revolution is usually dated from 1452, when Henry the Navigator gave his blessing to what is sometimes characterized as the island's first sugar mill. It was surely not the *first* mill. It was probably the first water-powered sugar mill, which would dramatically increase capacity, since we know that the island was producing 6,000 arrobas (84 tons) of sugar by 1454 (Pereira, 1969a: 82).[8] By the 1450's, modernity's first sugar revolution was in the offing. Sugar's ascent was wheat's decline. Sugar "had killed wheat," observes Serrão (1954), who sees the definitive transition from wheat to sugar in the 1470's. "Farmers growing crops [other than sugar] were quickly bankrupted" (Taylor, 2005: 41). Between 1454 and 1472, sugar production increased by over 230%, to 280 tons; by 1506, it expanded another 785%, to 2,480 tons (calculated from Schwartz, 1985; Pereira, 1969b: 454).

By the end of the fifteenth century, Madeira had displaced Cyprus from the commanding heights of the European sugar economy. Atlantic sugar was found everywhere from Antwerp to Augsburg to Istanbul (Galloway, 1977: 190–91). So great was this small island's revolution that it "cause[d] the distribution of sugar [to flow] more freely over the whole of European than had ever happened when the Mediterranean was the only supplier" (Deerr, 1949: 100).

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[7] This led, we might add, to the deforestation of several of the Azores in the seventeenth century (Tutin, 1953: 55).

[8] The Portuguese medieval *arroba*, in use until 1504, was 28 lbs. (Pereira, 1969a).

By 1530, however, sugar output had fallen to the production levels of the 1470's, a 90% decline. The decline after the 1506 peak was slow and steady for a few years. But at some point in the next decade, the sugar complex's underlying contradictions compelled a more dramatic contraction of output. Even in the face of rising world market prices for Madeira's sugar (O'Rourke & Williamson, 2002: 446–48), and no major competitors for the island's high-quality sugars (even after the rise of São Tomé in the 1540's), production continued its downward spiral. "If in 1547... the economy of the island was still based on bimodal structure of sugar/wine," by 1575 Vieira sees "the *total abandonment* of sugar cane" in favor of wines (1993: 10, emphasis added). An overstatement, to be sure (see Mauro, 1983), but it is one that highlights the essential movements.

What had happened? The fuel requirements of sugar were matched only by metallurgy in early capitalism (see Moore, 2007). And so the short answer is that sugar devoured the forests, and therefore the very conditions of Madeira's ascent also explain its rapid decline. But the short answer is easily misunderstood. The problem was not a scarcity of resources that eventually imposed an *exogenous* "natural limit" on Madeira's sugar revolution. Rather, the evisceration of the island's forests was the *historical* condition of success *and* crisis, actively produced in and through the emergent capitalist order of the first sixteenth century. The accumulation of capital won in Madeira through the phenomenal forms of environmental degradation, such as deforestation, enabled the world-historical advance of the sugar commodity frontier, next to São Tomé and Brazil.

There are two competing explanations for Madeira's decline. In the first place, historians of sugar and slavery attribute Madeira's decline from sugar primacy to competition from Brazil and São Tomé, even from the Canary Islands (e.g., Galloway, 1989; Klein, 1999: 14). It is an explanation that dates to the nineteenth century (White, 1851: 53). But there's a problem with the Smithian explanation. The timing just isn't right. Madeira's "rapid decline" spans 1516–37 (Albuquerque & Vieira, 1988: 29). By the 1530's production declined to a level not seen since the 1470's (Vieira, 2004: 48; also Deer, 1949, I: 101). In 1529, São Tomé was producing not more than 80 tons of sugar, and rather poor quality sugar at that. Brazil's sugar exports were modest until mid-century.

Historians of Madeira have offered a more compelling explanation of sugar's decline after 1506, one that weaves together world market forces and agro-ecological problems, labor scarcity, and even the impact of climate change on the island (Pereira, 1969a; 1969b; 1969c; 1969d; Vieira, 1993; 2004; 2009; Albuquerque & Vieira, 1996). This is a more compelling point of departure, and I will return to these socio-physical factors in accounting for the crisis of the sugar regime in Part II. Missing in these explanations is the devastation of the forests as cause and consequence of Madeira's rise and fall. While soil exhaustion stands as sugar's most commonly cited biophysical problem (e.g., Mintz, 1959; Castro, 1966), the exhaustion of forest resources—reinforcing and amplifying a broader repertoire of socio-ecological pressures inscribed in the sugar frontier—is the most likely pivot of production *collapse*. In the absence of catastrophic erosion, capitalist agriculture has proven adept in managing soil fertility. The management of forest resources, however, posed much tougher challenges.

This argument for forest crisis as constitutive of the rise and demise of Madeira's sugar complex is built out in two steps. In the rest of this section, I trace the ways that class, capital, and property mixed with the transformation of landscape to produce favorable conditions for the sugar revolution, even as signs of trouble became evident. Next, I demonstrate the plausibility of energy crisis as the pivotal factor in Madeira's decline.

## *Madeira in Monarchical Capitalism: How Monarchical? How Capitalist?*

Cyprus produced 800 metric tons of sugar at its peak in 1450, but less than half as much in 1500, a decline that owed much to deforestation (Ouerfelli, 2008: 130). Madeira's production, meanwhile, soared to more than six times its Cypriot competitors (Maddison, 2001: 60–61; Blackburn, 1997: 109). It was a changing of the guard, and not for the first time. Cyprus, home to the precocious agro-capitalism of Venetian merchant-planters a century earlier, could show, but not *lead*, the way (Solow, 1987: 714–15; Verlinden, 1970: 19–20). The signals of decline were surely evident to the Genoese, who in any event had been ousted from most of the Levant. It would be Genoese, not Venetian, capitalists who launched the modern sugar frontier, moving it westward to the Algarve in southern Por-

tugal, and thence into the Atlantic. By the 1490's, even Venice was drawing more sugar from Madeira than from established suppliers in Sicily, Cyprus, and Egypt; in the process Venice saw its lucrative trade with the English slip away (Giustiniani, 1519: 110–11).

Sugar inaugurated a revolutionary transformation of Madeira. Nevertheless, a key question remains. In what sense, or to what degree, was this a *capitalist* revolution? There are really two major ways to approach the question. The first is to sketch the connections from the standpoint of the emerging world division of labor. This is Wallerstein's approach (1974). Brenner calls this optic "ultra-Smithian" (1977), but it is by no means clear that viewing the world division of labor from the standpoint of world-economy is any more or less illuminating than viewing it from the standpoint of the production unit or region. It *is* certainly the case that the scalar vantage point—world-economy? point of production?—brings distinctive processes into view. Is there a way to weave the two scales together in a manner that moves beyond the banal invocation of a local-global dialectic? How might we take to heart the spirit, if not the letter, of Brenner's argument for the centrality of social property relations as the pivot of modern economic development, and weave this together with Wallerstein's persuasive contention that the rise of capitalism was part and parcel of an epochal reshaping of "world ecology" (1974: 44)?

Let me begin by stating my position simply. On Madeira in the "first" sixteenth century we find an island that was *becoming capitalist* even as it bore some resemblance to the socio-ecological organization of the medieval Mediterranean. It was becoming capitalist for three reasons. First, as we have seen, there was a secular trend toward rising commodity output. This was true not just in nominal terms, but also relative to the island, and to the Portuguese empire. Secondly, from the "first" to the "second" sixteenth century, there was no de-commodification, even as Madeira's sugar economy entered a protracted crisis in the 1520's. The island would quickly restructure around wine (Duncan, 1972: ch. 3). As early as 1560, Nicholas reported that Madeira, while producing some fine sugar, was "chiefly famous for its good wines" (1583: 557). Finally, the Madeiras were a crucial outpost in the construction of Portugal's global empire, one that had become "fully committed to commercial expansion" by the end of the fifteenth century (Greenfield, 1979: 116; also Malowist, 1964).

Madeira may not have been home to productivity-maximizing capitalist farmers akin to those of sixteenth- and seventeenth-century England and the Low Countries. But then, Madeira was a colonial zone, and heroic yeomen rarely populated colonial zones. The colonies of early capitalism were, however, in great measure the creation of plantations, and the Atlantic islands were testing grounds for this gruesome apparatus of territorial domination and commodity production. The word plantation conjures images of the great planters of seventeenth-century Brazil, or the cotton aristocracy of the antebellum American South. For this reason Galloway (1989), among others (Vieira, 2004), object to its application to Madeira. They rightly argue that production was small-scale, compared to later developments. But this is, after all, the point. The essential features of the model were in place: 1) the estate's dependence on finance and merchant capital, operating on a world-scale; 2) the slave form of production; and 3) its tendency to mine the soil and exhaust other forms of biophysical wealth, not least the laborers.

While medieval Cypriot sugar production was organized juridically as demesne land, among other things allowing European seigneurs to levy corvées from the local peasantry (Greenfield, 1979: 92), Madeira's colonization proceeded on a much different basis. The Portuguese Crown gave Madeira to Henry the Navigator as a colonial fief in 1433. But if this was feudalism, it was an exceedingly unusual form. For beginners, there was no parcellization of sovereignty. The Crown's courts retained the right to decide civil and higher criminal cases. The Crown retained its right to levy taxes (Verlinden, 1970: 207–08).

Perhaps most fundamental was the property system. The basic land grant unit on Madeira was the *sesmaria*, the size of which varied according to geographical conditions (Albuquerque & Vieira, 1988). "The law compelled landowners to cultivate their land under penalty of expropriation" (Verlinden, 1970: 219). Promulgated in 1375 on the eve of the Aviz Revolution (1385), the *sesmaria* was not so much a feudal social form as it was a specific socio-ecological response to feudal crisis. The fourteenth century witnessed an unprecedented concentration of landholding within Portugal, especially in the hands of the religious Orders (Marques, 1972: 112–13; Anderson, 1974: 172; Castro, 1970: 135–38). The *sesmaria* was a mechanism through which the Crown could promote (desperately-

needed) cereal cultivation on lands that were either unused or that had been converted to stockraising (Verlinden, 1970: 219). From this standpoint, the *sesmaria* appears as an assault waged by a precocious absolutist regime on parcellized sovereignty rather than a continuation of the latter.

On Madeira, *sesmarias* were given to settlers as land grants that could be held in perpetuity, "*provided that it was in cultivation within five years of receipt*. If cultivated, the land could be sold, given, and/or inherited as private property" (Greenfield, 1979: 99, emphasis added). Originally, the specific time frame was a decade. In 1433, it was changed to five years, in the 1440's to three, then to even shorter periods as the century wore on (Vieira, 2004: 50–51; Verlinden, 1970: 214). These measures created the basis for a land market, and consequently, for the emergence of a competitive property system that meted out dispossession as a penalty for poor performance. Indeed, once cultivated for the specified period, "the lord could not prevent the colonists from selling their lands and settling elsewhere" (Verlinden, 1970: 209). Of special import was Henry the Navigator's surficially feudal, yet powerfully commercializing, role in establishing the island's first major sugar mill in 1452. Henry reached an agreement with his "escuidero" (squire)—a certain Diogo de Teyve—to build this mill, a relation through which the prince would receive one-third of the produce. This was no lord-vassal relation. It was, rather, a contractual one: "The prince [Henry] himself called the agreement a *contract*" (Verlinden, 1970: 216, emphasis added). Crucially, Teyve could be dispossessed if he failed:

> [S]ugar producers *had* to allow mills and presses to work at full output.... If Teyve was successful he would enjoy a monopoly; if not, the Infante [Henry] could grant another contractor the right to construct a mill.... This contract had no trace of feudal or demesnial form. It started a sort of partnership between the Infante and his squire for the production of sugar on Madeira.... [This] was *the original deed of birth of sugar production on the island* (Verlinden, 1970: 217, emphases added).

Henry may not have been a capitalist entrepreneur, but he was certainly a territorial one who drank deeply from the well of Portuguese "state capitalism." The insistence on maximizing produc-

tion, coupled with a legal framework allowing land to be treated as a commodity and the Crown's increasingly accommodating attitude toward *resident* foreign merchants, explains something of Genoese capital's movement into production on the island during the 1480's. Genoese capital, and technical expertise from experience growing sugar in the Algarve,[9] had been present from the beginning (Fernandez-Armesto, 1982: 199). In 1455 the greatest sugar planter on the island was a Genovese. The last two decades of the century witnessed "at least six aristocratic Genoese families acquire extensive sugar plantations" on the island (Coles, 1957: 19; also Bovill, 1928: 22). By the early sixteenth century, fully two-thirds of the island's canefields were in the hands of "foreigners, especially Genoese and Florentines, or... New Christians" (Blackburn, 1997: 109; but see Rau, 1964).

It was this confluence of global capital, the *sesmarias*, and the expanding sugar market that created "the basis for social differentiation among the first colonists and opened the door to the growth of large-scale properties" (Vieira, 2004: 51). We needn't overstate the case. But neither should we understate it. The Crown proclaimed in 1496 that neither land, nor slaves, nor equipment could be seized for debts (Vieira, 2004: 59). But then, by this point a transition from independent proprietors to tenant farming was well underway (Albuquerque & Vieira, 1998: 24). The diffusion of tenancy, foreshadowing Brazil's sugar regime (Schwartz, 1973), meant that dispossession of real property was not much of an issue; farmers (as tenants) could be ejected from the land without any dispossession of property. And in any event, as was the case with forest regulation—which always indicated forest scarcity rather than its opposite—such proclamations *against* were just as surely recognitions *of* dispossession. Land, slaves, and equipment *were* being seized for debts on Madeira in the 1490's. Otherwise, there would have been no call for Crown intervention.

The island's economic sociology turned on a threefold division of labor: 1) merchant capital; 2) rich planters who owned *engenhos* (sugar mills); and 3) the majority of cultivators who owned land but not mills, and some who owned neither. (These latter would be called *lavradores da cana* in colonial Brazil.) These were over-

[9] Although it was certainly not just the Genoese. Many of Portugal's migrants to Madeira came from the Algarve.

lapping and fluid categories.[10] Merchants owned mills. Successful cultivators became millowners. The vast majority were cultivators, increasingly tenants, who by the end of the fifteenth century owned just a few slaves. Over half owned just one or two, and just 10% of slaveowners held more than ten (Vieira, 2004: 59). In the captaincy of Funchal, the island's capital, there were 14 *engenhos* but 209 cultivators in 1494 (Vieira, 2004: 53). The cultivators were a chronically indebted class. That is to say, they were in a position where they had to sell to survive, risking in the process either dispossession, or the debt-driven surplus squeeze of labor and land:

> Here, *even more than in [sixteenth- and seventeenth-century] Brazil*, there were many proprietors without the financial resources to set up the basic industrial operation of a mill and thus remained dependent on the services of the [*engenhos*]. . . . Direct sales, sometimes pledged before the harvest, were often used to pay existing debts. . . . *[Here] was a system that tended to subordinate the producers* (Vieira, 2004: 53, 70, emphases added).

No wonder that Koebel refers to the island's class relations in the early sixteenth century as one in which "bitter strife became frequent and general between the two classes," the cultivators and the millowners (1909: 20). Even earlier there were signs of conflict. In 1472, Portuguese cultivators on Madeira protested against Genoese hegemony in the sugar trade, complaining that cane farms "had been destroyed, damaged and lost owing to the presence of the Genoese" (Rau, 1964: 8). By 1494, there was widening inequality within the classes directly engaged in production. In that year, as the sugar boom stratified property holding, the top 4.5% of landowners produced 25% of the island's sugar, whereas the bot-

[10] The categorical overlap can hardly be overstated. "Merchant capital" must be comprehended as an accumulation strategy, one amongst many. Mercantile activities were primary at certain times and places, for certain clusters of business organizations, but the golden rule of capitalism nevertheless prevailed–follow the money, pursue the high-profit lines. Richard Pares' observation about the British West Indies in the seventeenth and eighteenth centuries is therefore scarcely less relevant to the earlier moments of the sugar commodity frontier: "It was characteristic of the fluidity of the economic relations in the sugar colonies at that time that a general merchant should be, at the same time or successively, a partner, a tenant and a landlord of sugar plantations" (1950: 41).

tom 75% produced just 30% (calculated from Galloway, 1989: 52).[11] Among the bottom 88 landholders (of 221), average output was less than 1.5 tons (Galloway, 1989: 53). Undoubtedly aggravating the political situation was the presence of putatively "foreign" planters at the top of the hierarchy. The gulf widened still further in the 1520's, as the sugar sector was gripped by crisis (Vieira, 1995).

Was there a "reproduction squeeze" that led producers to overexploit the soil? It is clear that the sugar revolution quickly generated a mounting volume of socio-ecological contradictions. At the very moment when the wheat regime definitively gave way to sugar, that is during the 1470's (Mauro, 1983: 206), conflicts escalated over water- and property-rights (Albuquerque & Vieira, 1988). Water and land became scarce as sugar advanced. Although the expansion of the *levadas* made more water available in absolute terms, demand outran supply.

The situation was much the same with land. During the 1470's "the policy of land concession [the *sesmarias*] ran into trouble... [and] the amount of arable land became more restricted" (Albuquerque & Vieira, 1988: 23). The proliferation of cane farms was so rapid that burning forest to create arable land was "recognised *as an ecological hazard and as a threat to the sugar economy*" (Albuquerque & Vieira, 1988: 23, emphasis added). There were escalating conflicts over the practice of burning, which often spread to neighboring cane fields (Vieira, 2004: 53–54). Access to the forest was progressively tightened, first in 1485, when the Crown "prohibited the distribution of uncultivated land in the hills and forests on the north side of the island" (Vieira, 2009: 12). In the next decade, a 1492 ordinance "imposed sanctions on those who dared to cut cedar and barbuzano," high-quality construction timbers (Magalhaes, 2009: 161). Next, firewood cutting was limited to property-owners and their agents (Magalhaes, 2009: 161). Between 1501 and 1508, the Crown ended the distribution of land through *sesmarias* specifically in response to the fuelwood demands of the sugar sector. The goal was to prevent, in Albuquerque and Vieira's words, "the *further* reduction of the forest area so necessary to sugar growing" (1988: 24, emphasis added).

[11] Albuquerque and Vieira provide modestly different figures: "The fifteen planters who made up 6.7 percent of all producers in 1494 produced 20 percent of output" (calculated from Albuquerque & Vieira, 1988: 25).

## DEFORESTATION AS THE PRICE OF SUCCESS: A HISTORICAL GEOMETRY

But why should it be so important to prevent the "further reduction of the forest area so necessary to sugar growing," precisely at the apex of the island's sugar boom? The short answer is that sugar consumed the forest at breakneck speed.

On Madeira's sugar output, we have reasonably solid figures (Pereira, 1969a; 1969b; 1969c; 1969d). In table 2, I reconstitute these into five-year, moving averages, and build out two major vectors of forest exploitation: the expansion of cultivation into the forest, and the expansion of fuelwood exploitation. These were two main ways that sugar advanced into the forest. The first was through the expansion of cultivation. Throughout the early modern history of sugar, new arable land was commonly won at the expense of forests, from the Atlantic islands to Brazil and the Caribbean (Moore, 2007). I have reasoned that only 20% of new arable land was subtracted from the forest, presuming that planters took advantage of our second vector of deforestation. This latter was through direct exploitation, to satisfy the construction and, above all, energy demands of the sugarmills. Demand for fuelwood was by far the greatest driver of forest clearance.

Madeira spans 741 km², of which about 60% (445 km²) was covered with dense *laurisilva* forests prior to colonization, along with cedars and red yew (European Environment Agency, 2002). Much of this forest was inaccessible. The island's dramatic vertical topography meant that between one-quarter and one-third of this forest was inaccessible to settlers in the "first" sixteenth century. Today, 150 km² of old-growth *laurisilva* survives, draping the mountains of the island's northern half (UNESCO, 2000: 93; Weijden & Pacheco, 2003).[12] How much of the original forest could be exploited by the settlers of the time? Given the prevailing technology, and the skills demanded to clear forest effectively, I am doubtful that we are looking at more than 300 km² available for commercial use. It is one thing for a peasant to cut fuelwood for the home, quite another to feed the maw of a sugar complex disciplined by the world market.

[12] This "main forest is believed never to have been felled or cut and includes some massive old trees . . . over 800 years old" (UNESCO, 2000: 94).

**Table 2**
Sugar and the Fate of the Forest, Madeira, 1445–1509
(Five-Year Averages, in Hectares)

| | Canefields (from forest) | Sugar Production | Deforestation for Fuelwood | Cumulative Deforestation |
|---|---|---|---|---|
| 1445–49 | 200 | 40 | 67 | |
| 1450–54 | 300 | 60 | 100 | |
| 1455–59 | 450 | 90 | 150 | |
| 1460–64 | 600 | 120 | 200 | |
| 1465–69 | 900 | 180 | 300 | |
| 1470–74 | 1,350 | 270 | 450 | |
| 1475–79 | 2,025 | 405 | 676 | |
| 1480–84 | 3,050 | 610 | 1,016 | |
| 1485–89 | 4,000 | 800 | 1,333 | |
| 1490–94 | 5,000 | 1,000 | 1,667 | |
| 1495–99 | 6,000 | 1,200 | 2,000 | |
| 1500–04 | 7,500 | 1,500 | 2,500 | |
| 1505–09 | 9,500 | 1,900 | 3,167 | |
| Total | 10,500* (1,900) ha | N.A. | 13,626 ha | 15,526 ha |

*Includes an additional 1,000 hectares to compensate for declining land productivity.

Sources: Cadamosto (1455); Pereira (1969a; 1969b; 1969c; 1969d); Miller (1994); Moore (2007: chs. 5, 6); Rau (1964).

Early modern deforestation is one of those problems easy to assert and difficult to prove. Castro concludes that sugar pushed the island's forests toward "total degradation," leading to a "collapse" in production by the 1530's (2002: 105; also Carita, 2006). It sounds good. But is it *true*? Like the debate over American silver and the rise of capitalism, the question of the relation between forests, energy, and capitalist development has sustained research and debate for nearly a century (see, *inter alia*, Allen, 2003; Flinn, 1958; 1959; Cipolla, 1976; Clow & Clow, 1957; Hammersley, 1973;

Malanima, 2006; Moore, 2007; 2010a; 2010b; Nef, 1932; 1950; 1964; Sombart, 1921, II, ii: 1145–48; Thomas, 1986; Warde, 2003; 2006; Westoby, 1989; Wilkinson, 1973; Williams, 2003). Given the long-standing interest in the "forest-energy question," it is therefore surprising that so little attention has been given over to the key technical questions of forest exploitation, potential energy yield, the fuel consumption of energy-intensive manufactures such as sugar, and technical innovations that set the "limits of the possible."

How can we *know* the extent of forest clearance and its effects? In this section, I focus on a set of quantitative extrapolations based on sugar production figures, fuel consumption, forest yield, and agricultural productivity. My aim is to establish the plausibility of the interpretation. If handled delicately, the *geometrical* representations of environmental transformation that emerge from these extrapolations can serve as useful heuristic guides for the explanation of changing environments (at multiple scales) and economic development broadly conceived. Such historical geometries are crucial to the construction of historical *geographies* of the early modern world, and its commodity frontiers above all. In the next installment of this essay (Part II), I will take this historical geometry to explore Madeira's deforestation and its implications for sugar's decline and their impact on the Portuguese Empire and the emergent capitalist Atlantic.

### *Agricultural Productivity and the Forest*

Because sugar monocultures tended to exhaust soil fertility, throughout the early modern era there was a strong frontier movement, not only across the Atlantic world, but also within the sugar zones themselves. This emphatically modern frontier movement brought together the triple commodification of land, labor power, and sugar in the formation of sugar booms. In Part II, I will take up the pivotal question of declining *labor* productivity in agriculture. For the moment, let us focus on the relation of arable land and forest clearance—sugar and land. This of course is an age-old relation, and the rise and demise of feudal Europe can be read through the advance of arable land and the retreat of the forest (Moore, 2003b; Williams, 2003).

Three distinctive features of Madeira's "first" sixteenth century provide an arresting contrast with feudal Europe. First, the

emergent disciplines of capital led to an acceleration of biophysical exploitation, manifesting an accelerated cycle of planting, exhaustion, and the search for new arable land, frequently carved out of the forest. There was a "metabolic rift" immanent to the earliest moments of the transition to capitalism, as nutrients were removed from the soil and shipped to distant urban markets (Foster, 2000; Moore, 2000a). The conversion of forest to arable land provided a crucial means of attenuating the systemic tendency toward nutrient depletion, which explains something of the close link between agro-ecological exhaustion and deforestation in early capitalism (Moore, 2007; Moore, 2010b). Sugar cultivation engrossed some 10,500 hectares by 1509, more than half the island's potential arable land. Of this, 1900 hectares had been claimed from the forest even before fuelwood extraction is brought into the equation.[13]

Secondly, the temporal disciplines of the law of value and its metabolic rift compelled not only an acceleration of nutrient depletion relative to medieval norms, but new landscape disciplines. This meant monoculture above all. As we will consider in more detail in Part II, monoculture was a powerful strategy of increasing labor productivity over the short run, at the same time as it created fertile environments for the very weeds and pests that undercut productivity gains over the middle run. Thirdly, while much of the technological apparatus remained the same, sugar production was now integrated into systemwide financial circuits that unified (however tenuously) production and exchange in northern Europe, Braudel's "global Mediterranean" (1972), and an expansive if diffuse capitalist Atlantic. The capitalist circuit of accumulation (M-C-M+) increasingly dominated the rules of reproduction for sugar production and trade; sugar's "natural distinctiveness" existed as something to be dissolved into the "abstract generality" of money capital (Marx, 1973: 141).

These three tendencies were magnified further by Madeira's geography. Madeira's potential mass of arable land was exceedingly modest. In contrast to Barbados two centuries later (Dunn, 1972), room for expansion into the interior was limited. Where Barbados is unusually flat, Madeira is essentially a mountain rising up out of the ocean. On the southern coast, cane might climb

[13] Assuming that 20% of new cultivation expanded into the forest, and that forest clearance for fuelwood and construction needs accounted for the remainder. See below for further discussion.

the mountainsides as far as 400 meters, but no farther—and such elevations were typically reached within three kilometers from the shore. Albuquerque and Vieira see a 2.5-kilometer "corridor [of arable land] parallel to the coast" (1988: 23). This corridor varied considerably, shaped by differing microclimates on the northern and southern coastlines, comprising in their view a theoretical maximum of 300 km² (Albuquerque & Vieira, 1988: 23). This is probably too generous. The island stretches 50 kilometers east to west with a steep incline virtually everywhere (Calvert, 1979: 45). A maximum of 200 km² of potentially arable land is probably closer to the mark. This was, in any event, the area under cultivation in the mid-twentieth century (Câmara, 2006: 217).[14] And of course, all land was not equally desirable, especially land even a few kilometers distant from rivers or *levadas*, and much of it was covered with forest.

The "work" of the forest in sustaining agricultural productivity merits some explanation. For all the attention given over to the "Columbian Exchange" and the biological invasions of the European expansion (Crosby, 1972; 1985; McNeill, 2003), the tremendous windfalls enjoyed by the cultivators of new crops such as sugar is often missed. These windfalls constituted, in Dark and Gent's nicely turned phrase, "yield honeymoons" (2001). Exogenous crops enjoyed a "honeymoon" of high yields—above and beyond the fertility bonus of uncultivated soil. If new settlers could clear forest rapidly, a new wrinkle emerges. New arable land cleared from forest would have "few weeds [and few sources of fungal pathogens] at first, as potential seed sources would have been few, while the landscape remained predominantly wooded" (Dark & Gent, 2001: 73). We may recall Cadamosto's report of wheat yields of 70:1 (1455: 9). While probably inaccurate, it is also probable that the report contained a kernel of truth. Far from exceptional, we have reports of extraordinary yield windfalls throughout the Americas in the colonial era (Super, 1988).

Recurrent yield honeymoons, under conditions of export monoculture (highly favorable to pests, weed, and diseases), accelerated nutrient uptake from the soil and accelerated the evolu-

[14] "No minute piece [of land] seems to be wasted, and many an odd corner and neglected patch which, from its steepness or the poor quality of its soil, escaped cultivation in years gone by, . . . has [recently] been . . . pressed into service" (Du Cane & Du Cane, 1909: 97).

tion of weeds and pests. Weeds were an especially big problem; they evolved quickly and proliferated even more rapidly. Weeding sucked up huge amounts of labor once the honeymoon was over. A Brazilian source from 1753 identifies weeding as labor-intensive as planting, and an activity that required as much labor as the cutting and carting of cane *combined* (Schwartz, 1985: 142; also Watts, 1985; Peng, 1984; for Madeira, see Mauro, 1983: 206). It is entirely possible that the nutrient demands weed populations created through sugar monocultures greatly outweighed those of the cane itself. Weeds and weeding may have proved a much more formidable barrier to maintaining and improving labor productivity in agriculture than commonly recognized. To the extent that cultivators are unwilling or unable to withdraw from the world market—and indebtedness enforced by the state would play an enduring role in the history of sugar—there would be mounting pressure to find new land upon which to enjoyed a second (and third and fourth . . .) honeymoon.

What was land productivity during Madeira's sugar boom? Two big questions immediately present themselves. First, how much would a hectare, planted in cane, yield? Secondly, how much sugar could be extracted from a given mass of raw cane? A higher extraction rate in the post-harvest processing phase could make good any difficulties in cultivation.

We begin with the passage from cane to sugar. The ecology of sugarcane mandates processing within 48 hours—the sooner the better. Raw cane could not be shipped off the island. There were of course many grades of sugar, and semi-refined sugar was commonly exported for additional processing to Lisbon, Antwerp, and Genoa. The crucial point concerns the rate of extraction, the amount of (semi)processed sugar that was produced from raw cane. My bias here favors a highly efficient rate, which underestimates deforestation.[15]

There is no systematic study of the relation between technology and the rate of extraction in the early modern sugar complex. Making sugar was treacherous work, and every improvement in the rate of extraction was won from decades, even centuries, of experimentation (Galloway, 1989). On Barbados, the rate of ex-

[15] The manufacture of high quality sugars, such as that used in pastries, would result in substantially more bulk reduction, by as much as one-third, and therefore a lower (less efficient) rate of extraction (Vieira, 2004).

traction reached 3.1% in the 1840's (calculated from Simmonds, 1854: 138). By the later nineteenth century, extraction rates varied between 4 to 5.5% (Eisenberg, 1974: 126; McCook, 2002: 80). In Cuba, the higher figure was obtained by deploying steam power and a three-roller mill, neither of which could be found on Madeira in the "first" sixteenth century. Even in the twentieth century, extraction rates rarely hit double-digits; Louisiana's was just 8.6% in the 1950's (Humbert, 1968).

What was Madeira's extraction rate in the "first" sixteenth century? We can begin with the prevailing technology. Warren Dean thinks a 3% extraction rate was standard in late seventeenth century Brazil, although this seems optimistic. The level of efficiency realized by the Brazilian *engenhos* was achieved by the vertical three-roller mill, an important technological innovation introduced during the 1610's (Barros de Castro, 1980). For our purposes, we can observe that the three-roller mill was two major steps ahead of Madeira in the fifteenth century. The conventional narrative places the two-roller mills on Madeira, from the 1450's. John and Christian Daniels (1988), however, find no evidence for two-roller mills on Madeira before the 1520's. Even then, these were horizontal rather than vertical mills—and therefore susceptible to the re-absorption of cane juice into the *bagasse*—and were uncommon until mid-century (Daniels & Daniels, 1988: 514). It is unlikely that the two-roller mills exceeded a 2% extraction rate.

But if two-roller sugar mills did not appear on Madeira until the 1520's, what was the prevailing technology at the dawn of the island's sugar boom? On Madeira in the 1450's, the cutting edge of sugar mill technology was the "edge runner," a mill common to the medieval Mediterranean (Daniels & Daniels, 1988: 514). The edge runner was essentially a large, heavy wheel capable of crushing the raw cane, from which the juice would run into a basin. It could be powered by water or animals. Additional juice would then be extracted in presses similar to those used for olive oil. These had long been used to process sugar in the Mediterranean world. The extraction rate was exceedingly low, in my estimation not more than one percent.

The sugar-to-cane ratio offers a starting point for the historical geometry of sugar's expansion. Our next step is to consider land productivity. The best estimates are from the nineteenth century. Fresh land in Cuba during the 1870's yielded "as much as 119 tons

of cane" per hectare (Eisenberg, 1974: 218). In the same decades, yields in Pernambuco (Brazil) "never exceeded" 60 tons, or annual productivity of 40 tons/hectare (Eisenberg, 1974: 218, 126). Jamaican production in the mid-nineteenth century was 51.6 tons/ha (calculated from Ure, 1853: 758).[16] And 50 tons/hectare was standard for Pernambuco canefields in the seventeenth century (Dean, 1995: 79). Indeed, 50 tons/hectare is the average for Pernambuco today (Porter, Dabat & de Souza, 2001: 833).

What, then, were sugar yields in fifteenth century Madeira? I would begin with Dean's estimate of 50 tons/hectare in seventeenth century Pernambuco. Northeastern Brazil had two great biophysical advantages over Madeira. First, it was warmer and wetter; irrigation was unnecessary. Secondly, Pernambuco's soils, especially the famed *massapé*, were more fertile. The manuring practices common to Madeira's and São Tomé's sugar cycles were unnecessary in Brazil (Dean, 1995: 56). In this light, any estimate of Madeiran sugar yields greater than 40 tons/hectare seems unrealistic.

Land productivity is usually reckoned in annual cycles. But planted cane is not an annual crop. In early modern Brazil and the Caribbean, time to maturity varied between 14 and 18 months. In Madeira and the Canaries, the harvest cycle was closer to two years: "good Soil yields nine Crops in eighteen Years" (Nicholas, 1583: 536; also Landi, 1530: 85). A harvest of 40 tons/ha translates to annual land productivity of 20 tons/ha. Now, replanting was not always necessary. Stalks could be left in the ground to resprout, a process called ratooning. In Brazil and the Caribbean, ratoons matured faster than transplanted cane, taking about twelve months to ripen, but characteristically with a lower yield than cane freshly planted. Thus ratooning, in these estimates, does not alter the land productivity estimates (Schwartz, 1985: 109; Landi, 1530: 85).[17]

From this reading of sugar's history, we can safely estimate that 9500 hectares were planted in cane at the apex of Madeira's sugar boom in 1505–09. But this holds only if we hold constant land

[16] Calculated from Ure's estimate of 7 hogsheads, of 16 cwt each (112 lbs/cwt), for 10 acres (1853: 758), assuming a 3% extraction rate (also Simmonds, 1854).

[17] In the favorable climate and soil of northeastern Brazil in the sixteenth and seventeenth centuries, ratoons were known to give comparable yields for the first and sometimes second ratoon crops (Schwartz, 1985: 109). Not so in sixteenth-century Madeira (Landi, 1530).

productivity, which we know was not constant. (About which, we shall hear more in Part II.) By 1500, the yield honeymoon of the early decades of cash-cropping had passed. We have no reports of the precise *rate* of yield decline for Madeira. Fortunately, these are available for Barbados and Jamaica in the seventeenth and eighteenth centuries. In Barbados between 1649 and 1690, the volume of sugar produced on one acre fell by at least one-third (Barrett, 1979: 22). But the aggregate figure obscures profound unevenness. On those plantations established during the initial boom of the 1640's, yields declined by as much as one-half by 1685 (Watts, 1987: 397). The same thirty-year cycle is discernible for Jamaica. The island's Bybrook plantation, for example, saw output fall from more than 100 hogsheads to just 50 over the last three decades of the seventeenth century. Bybrook, "not yet thirty years under cultivation . . . was nearly worn out and worth very little" (Dunn, 1972: 219–21). Charles Lesley observed in the 1730's, not more than a half-century after Jamaica's sugar boom commenced, that "Acres of Cane require almost Double the number of Hands they did formerly, while the Land retain'd its natural Vigour" (1740: 337). If a thirty-year cycle of intensive cultivation during the boom years of the 1470's led to a 50% decline in yields, we can tack an additional 1,000 hectares onto our estimate of arable land, for a total of 10,500 hectares of cane planted by 1509.

## *Sugar and the Forest:* Engenhos *of Destruction*

Cultivation's advance into the forest paled next to the sugar frontier's greatest vector of deforestation, fuelwood exploitation. To say sugar is to say deforestation. This was an enduring eco-geographical structure of the modern world-system well into the early twentieth century. (Indeed, as the ethanol revolution gathers steam today, one wonders if the formula ever disappeared.) Once the forests of Madeira, northeastern Brazil, and the Caribbean had been razed, the same pattern was reproduced with the extension of the sugar commodity frontier to Mauritius, Australia, and the Philippines, among other places (Griggs, 2007; Tucker, 2000). At the heart of early modern sugar's ecological vulnerability (*and* its economic dynamism) was the tendency to exploit forests beyond their capacity to renew themselves.

To make one pound of sugar required *no less* than 50 pounds of fuelwood (and this is a conservative estimate). Nearly 700 hectares of forest were sacrificed in 1506 alone to produce that year's bumper crop of 2480 tons of sugar. This was not forest exploitation along the lines of early modern coppicing, such as practiced (unevenly) in England. This was 700 hectares of forest *cut down*. In one year.

Making sugar takes a lot of energy. Its closest counterpart in this era was ironmaking. The estimate that I settled upon for table 2 is a sugar-to-fuelwood ratio of 1:60. This is considerably higher than the two estimates which have gained the widest circulation among environmental historians—Perlin's estimate of 1:46 (1989), and Warren Dean's reckoning of 1:15, in his classic study of the destruction of Brazil's Atlantic forest (1995: 80). The estimates are worth discussing, because the technical details shape our understanding of the enormity of the epochal shift in nature-society relations during the "long" sixteenth century. They are also worth discussing because, as the history of sugar emerges as a crucial site of modern environmental history (Hollander, 2008; Monzote, 2008; Moore, 2007), the quantitative moment of sugar's tendency toward deforestation has not been sufficiently researched. Dean offers no source for his estimate, but Perlin does, and this is worth considering.

Perlin's guesswork has the virtue of drawing upon an eighteenth-century Brazilian source (Couto, c. 1759). Couto's observation of sugar's fuel requirements is phrased in relation to the *pães*, the sugar loaf or "form" that results once the sugar is boiled down and poured into clay pots. The size of these loaves varied. In early colonial Brazil, the standard *pães* was 1–2 arrobas (15–30 kilograms); after the 1660's, this grew to 2–4 arrobas, which became standard in Bahia (Schwartz, 1985: 113). There is, however, a world of difference between two and four arrobas. Two arrobas translates to sugar-to-fuelwood ratio of 1:50; three arrobas, to 1:33; four, to 1:25. The largest mills tended to produce the largest loaves, but these big mills became increasingly *un*representative in the century after 1627. This was a period characterized by the rapid growth of small mills. Output per mill fell by nearly half between 1627 and 1710 (Moore, 2007: ch. 6).

If sugar manufacture demanded so much more fuel than even Perlin suggests, this ought to show up in the evidence drawn from

multiple sites across the early modern sugar archipelago. In eighteenth century Brazil, Lisboa suggested a ratio of one unit of wood for every unit of raw cane, which gives us a sugar-to-fuelwood ratio of 1:100 for an extraction rate that hovered around 1% for sixteenth century Madeira (Lisboa, 1786: 47–50, quoted in Padua, 2000: 269–70). Elsewhere we find very high estimates, although lower than 1:100. If we take the primary source figures provided by Miller (1994) and Schwartz (1985), we find considerable support for the higher estimate. In Bahia during the 1750's (1758), Miller puts the *engenhos*' aggregate fuel consumption at 3,348 $m^3$ *every day*, or 750,000 cubic meters a year, assuming 224 milling days (1994: 184). If 200 milling days was closer to the mark,[18] then Bahia's annual consumption would come to 669,900 $m^3$ a year. (If fuelwood harvesting proceeded at a rate of 180 $m^3$/ha, the rate of effective deforestation was 2977 ha/year.) The nearly 670,000 $m^3$ of wood translates to 536,657 tons, a figure we can place in dialogue with Schwartz's estimate of 400,000 arrobas (6,525 tons) of sugar produced in Bahia during 1758 (1985: 423). This gives us a ratio of sugar-to-fuelwood of 1:85. If we assume that none of Bahia's mills shut down from lack of fuelwood and therefore a 224-day rather than 200-day year, this brings the ratio down to 1:80 (see also Williams, 2003: 216); but it is doubtful that a 224-day work year was reached on a consistent basis. If 1:60 is a high estimate relative to Perlin and Dean, even higher estimates are not only possible, but probable. Nevertheless, I have opted for a conservative bias that underestimates the likely extent and pace of deforestation.

Sugar's energy demands can now be put into relation with the yield of the forest. This is a socio-ecological question. Even a provisional answer hinges on the biophysical matrix of the forest itself, and the socio-technical regime that takes shape around the latter's exploitation. Yield, in other words, is a historical question that in-

[18] "The adequate construction of reverberatory hearths would solve this problem, . . . of the immense quantity of wood wastefully employed[,] . . . which causes great losses to farmers and masters of mills, because those who do not possess large forests do not manufacture sugar and those who do have such forests in the future will let their mills go idle on account of lack of firewood, *because this is confirmed by experience*" (Lisboa, 1786: 47–50, order of quotation slightly altered). Even in the absence of serious fuelwood problem, there were many days lost out of the theoretical maximum of 291. In the first half of the seventeenth century, the Engenho Sergipe lost 78 days (only five of them from woodfuel supply problems), bringing the number of production days to 211 (Schwartz, 1985: 101–02).

terweaves the domains of net primary productivity and labor productivity, flows of capital and the contest of classes. How much there was to extract, and how much could be extracted under definite historical conditions. To safeguard against overstating deforestation, I have abstracted other socio-ecological demands on the forest. For instance, the 18,000 people living on Madeira by 1500 (Blackburn, 1997: 109) consumed no less than 18,000 cubic meters of fuelwood each year—about 80 hectares—*just for domestic purposes*! And while forests can regenerate, given time, Madeira's sugar revolution unfolded so rapidly that there was little opportunity to do so.

How much fuelwood could be won from a hectare of Madeira's forest? Here again, the eco-geometric estimates that are the basis for debates on forest crises have often been treated too casually (e.g., Hammersley, 1973).[19] In table 2, I put average yields at 180 tons/225 $m^3$ of wood per hectare, assuming 1602.2 lbs/$m^3$ of hardwood.[20] My estimate draws on primary sources and the forestry literature. Our best documentary sources for fuelwood extraction are from nineteenth-century North America, which give us a range of 15–50 cords/acre, or 134–447 $m^3$/ha for the northern United States (Marsh, 1864: 151; Sargent, 1884: 497, 502, 552, 555, 559; also Whitney, 1994: 145, 213). The middle range estimate of 225 $m^3$/ha—about 25 cords/acre—fits well with the working estimates among environmental historians (Williams, 2003: 532n; Brannstrom, 2005). It also fits nicely with the forestry literature, which suggests a density—not to be confused with actual yields—closer to 300 $m^3$/ha for "old growth" temperate forests and

[19] To this day, Hammersley's essay is widely regarded as the benchmark for discussions of forest crisis in eighteenth-century England (1973). Hammersley's position was that forest regeneration was sufficiently vigorous that any talk of a generalized forest crisis—propelled in great measure by the demands of the country's ironworks—is unwarranted on empirical grounds. The difficulty is that Hammersley relied on precisely one source (Taylor, 1946) as the basis for his estimate of forest regeneration (net primary productivity, in the language of forest ecology). Taylor argued that, under conditions of managed growth, coppiced forest could generate *as much as* 100 cubic feet/acre every year, which translates to nearly 7 $m^3$/ha. The issue is fourfold. First, Taylor was writing about forestry practices two centuries after the period that Hammersley examines. Secondly, Taylor's estimate was a *maximum* figure. Thirdly, we find multiple sources that find a much lower rate of annual increment—somewhere in the range of 2–3 $m^3$/ha was the average (see Moore, 2007a: ch. 2; also Fernow, 1911; Lindsay, 1976; Williams, 2003).

[20] Premised on a working assumption of one hardwood standard cord at 5800 lbs. (see Moore, 2007a).

250 $m^3$/ha for their tropical counterparts (Holland, 1973: 972). Although an imperfect analogue to the hardwoods of fifteenth-century Madeira, old growth Douglas fir stands in the American Pacific Northwest today offer a harvestable potential of 293 $m^3$/ha (Prudham, 2005: 61). For coastal British Columbia, estimates fall in the same range, 275–325 $m^3$/ha (British Columbia Ministry of Forests, 2007). European foresters have arrived at a similar ballpark figure, identifying an upper limit of 287 $m^3$/ha (Nabuurs et al., 2007: 396).[21]

There lies a rather wide gulf, however, between theoretical maximum and attainable yield.[22] For starters, cutting trees was dangerous work (Dean, 1995: 182–83; also Watts, 1987: 185–86; Bridenbaugh & Bridenbaugh, 1972: 42–43, 268–71; Moore, 2007a: ch. 6; Schwartz, 1985: 141). Beyond the inherent dangers of logging, the technology was crude and not all timber was equally suitable for firewood. Large trees on Madeira would have been difficult to fell and then haul. If Madeira's hydrology changed enough during this period to limit river flows (Grove, 1995: 29; Mason, 1850: 162), transporting timber would have become even more costly. Beyond this, there was the labor of chopping the wood into parts small enough to generate sufficient heat; large—and worse, unseasoned—parcels were useless (Antonil, 1711: 202–03; also Miller, 1994; Brannstrom, 2005).

## BY WAY OF CONCLUSION: THE CONSEQUENCES OF ASCENT

Even when we deploy a set of cautious estimates, the cumulative geometry of deforestation is huge, amounting to over 15,500 hectares by 1510. Domestic fuelwood demands alone—never mind construction demands—would have added another 800 hectares in

[21] Other European reports indicate a stocking rate of 300–450 $m^3$/ha for 130-year-old oak and beech outside Vienna (Lewis et al., 2004). These elevated figures occur under highly managed conditions, and should not be regarded as typical.

[22] Extraction from European woodlands, moreover, was significantly lower. Mulhall, looking at late nineteenth-century Europe, suggests 1000 cubic feet per acre of forest "if cut down" rather than coppiced (1899: 297). Using his metric, which puts the weight of one cord (128 cubic feet or 3.62 $m^3$) at 5000 lbs rather than 5800, this translates to 2,470 cubic feet/ha or 48.24 tons/ha. This contrasts with our much higher figure of 180 tons/ha.

this first decade of the sixteenth century. No wonder that by the early sixteenth century, "the hills surrounding Funchal [the island's capital] were barren" (Vieira, 2009: 12). On an island where labor was costly and labor productivity low, and where sugar's appetite for fuel remained very high, the removal of more than half of Madeira's accessible forest by 1510 represented a major challenge to the sugar regime.

One might well ask if the foregoing historical *geometry* has gone too far? My sense is precisely the opposite, that the geometrical analysis deliberately understates the era's transformations. While the details of Madeira's sugar crisis will be elaborated in Part II of this essay, for now we may conclude with some geographical morsels to complement the cool calculations of our geometry. Amongst these possible morsels, we find successive extinctions of endemic mollusks during the first two centuries of settlement (Goodfriend, Cameron & Cook, 1994). The earliest extinction occurred in the beginning of the sixteenth century (1994: 315–18). The cause?

> Habitat disturbance is mostly likely the cause of most or all of the extinctions.... *With the coming of man to the island, there was a rapid and large-scale change in the habitat, from woodland to grassland*, with major effects on both species composition and relative abundances....There was a loss of *most of the woodland species*, presumably mainly as a result of physiological stresses [such as deforestation]. There was also a relative increase in the grassland element (Goodfriend, Cameron & Cook, 1994: 318, emphases added).

Madeira points us towards a new ecohistorical pattern that began to cohere after 1450, at the beginning of Braudel's "first" sixteenth century, and part and parcel of the rise of capitalism not only as world-economy, but as world-*ecology* (Moore, 2003c; 2010a; 2010b; 2010c). It was an unusual pattern indeed, and one that the sugar commodity frontier pioneered in decisive ways. To put it schematically, after 1450 across the spaces of the European economy, production centers were locked in a competitive struggle through which victory was achieved by maximizing and accelerating the extraction of wealth from land and labor. I am not convinced that this early modern ecological revolution was a narrowly Smithian phenomenon, as if the commercializing impulse had been stilled during the fourteenth-century crisis, waiting to burst

its medieval carapace. Such is the perspective articulated by some of our most influential environmental historians (Merchant, 1980; Hughes, 2001; Richards, 2003). Would it perhaps be more fruitful to situate commercialization as rather more consequence than as cause? My preference is to situate the cascading ecological revolutions of the early modern era within a more expansive competitive dynamic specific to the conditions of Europe's emergence from the socio-ecological crisis of the "long" fourteenth century—conditions that had as much to do with agrarian class structures and the Continent's state machineries as they did with concentrations of economic power. Over time (much less time than ever before), this emergent ecohistorical pattern, increasingly modern in its intensive and accelerating movements, led to the *relative* exhaustion of the relations governing the provisionally stabilized matrix of human and extra-human nature. Successive regional sugar complexes thereupon faltered as relative exhaustion undermined the conditions necessary to sustain a competitive position in the world market. Thence renewed the search for new, more fertile zones of production—from Madeira we move to São Tomé, Brazil, the Caribbean.

The rise of capitalism as world-ecology effected two world-historical ruptures of signal importance after 1450. The first rupture was centrally concerned with reworking time, the second, with revolutionizing space. First, *history moved faster.* Under the new regime, ecological wealth—from forests, fields, mines, and communities (qua labor power)—would be extracted in the quickest way possible. (Extracted, we should note, from these agrarian spaces and conveyed into urban-centered production and accumulation.) The rapid extension of commodity relations to frontier zones tended to produce, at first, great booms, and later, to undermine the socio-ecological conditions of production and therefore, eventually, the conditions of profitability. As with other leading commodity frontiers pivoting on silver, copper, iron, and forest products, successive sugar zones enjoyed their moment in the sun for but a short time. Typically, this was somewhere between 50 and 75 years. The contrast with the medieval Mediterranean is instructive. Sugar, cultivated on a large-scale in the Levant, Cyprus, and Sicily, evinced no strong tendency toward an accelerated cycle of boom, bust, and geographical relocation (Galloway, 1977; Solow, 1987; Verlinden, 1970). The movement was slower, incremental—in

other words, essentially medieval. This Mediterranean pattern was as different from the modern sugar complex as feudalism's settler colonialism was to Europe's overseas expansion.

This acceleration of historical process was inseparable from our second rupture, the expansion of the geographical arena. This was in fact the (slightly paradoxical) precondition for the geographical concentration of production on islands such as Madeira. A quantum leap in the production of time necessitated a quantum leap in the production of space. Madeira's sugar revolution was thinkable only through the successive movements of capitalist advance—in the direction of the Azores, the Canary Islands, São Tomé, and of course, West Africa.

Madeira's crisis coincided with massive deforestation. This much is certain. But correlation is not causation. It is not exactly news that sugar production and deforestation were intertwined. The geometrical representations we've reviewed provide a working hypothesis. But they are only suggestive, not conclusive. I do believe that fuelwood supplies constituted sugar's greatest vulnerability—on Madeira, to be sure, but not only on Madeira. It was a vulnerability common to the early modern sugar frontier in general (Moore, 2000b; 2007: ch. 6). Nevertheless, to focus on this or that moment of environmental change may fall wide of the mark. For the era's commodity frontiers—Brazilian sugar, Peruvian silver, Norwegian timber—rose and fell on the strength of the totality of socio-ecological relations governing commodity production, on the vitality of their *ecological regimes* (Moore, 2007; 2010a; 2010b). Thus, the crucial discussion turns on the exhaustion of the Portuguese Empire *as* ecological regime, and the erosion of that regime's capacity to compete effectively on the era's "vast but weak" world market, *itself a socio-ecological formation*. These themes I will pursue in Part II.

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