Moore, Jason (2010) '"This lofty mountain of silver could conquer the whole world": Potosí and the political ecology of underdevelopment, 1545-1800',
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"This lofty mountain of silver could conquer the whole world": Potosí and the political ecology of underdevelopment, 1545-1800[1]

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Abstract: By the 1570's, Potosí, and its silver, had become the hub of a commodity revolution that reorganized Peru's peoples and landscapes to serve capital and empire. This was a decisive moment in the world ecological revolution of the long seventeenth century. Primitive accumulation in Peru was particularly successful: the *mita*'s spatial program enabled the colonial state to marshal a huge supply of low-cost *and tractable* labor in the midst of sustained demographic contraction. The relatively centralized character of Peru's mining frontier facilitated imperial control in a way the more dispersed silver frontiers of New Spain did not. Historical capitalism has sustained itself on the basis of exploiting, and thereby undermining, a vast web of socio-ecological relations. As may be observed in colonial Peru, the commodity frontier strategy effected both the destruction *and* creation of premodern socio-ecological arrangements.

Keywords: world-systems analysis, environmental history, political ecology, capitalism as world-ecology, political economy

Introduction

The Spanish "discovery" of Potosí in 1545 ranks amongst the signal events in modern world history. By the 1570's, the Cerro Rico ("rich mountain") was the epicenter of a commodity revolution that reorganized Peru's peoples and landscapes to serve capital and empire. The silver that flowed from the Cerro Rico's open veins was directly linked to a new era of world capitalist development— Fernand Braudel's "second" sixteenth century (1953)— inaugurated by the financial crisis of 1557. It was a crisis that owed much to Castile's declaration of bankruptcy that year, and its successive fiscal crises would set in train the imperial restructuring of Peru by 1568. Capitalism's "second" sixteenth century would be led by the Dutch Republic, and Dutch capital depended on the ready cash (silver) that Potosí supplied. The flipside of Potosí's extraordinary role in delivering a material basis for money capital-formation was the radical transformation of land and labor in the service of world accumulation. This was a decisive moment in the world ecological revolution of the long seventeenth century (Moore 2010b), whose effects reached from Potosí to Southeast Asia to the Baltic.

Theoretical framework: the commodity frontier in the rise of the capitalist world-economy

The place of American silver in the rise of capitalism has been well-studied and ably debated for much of the past century (Hamilton 1934; Flynn and Giraldez 2002). It is sometimes recognized that profound environmental transformations ensued from early modern silver production (Galeano 1973; Dore 2001). But rarely is it understood that the rise of capitalism was a world-ecological project and process *in itself*. Capitalism did not emerge as a set of relations between humans, but rather through the nexus of human interaction with the rest of nature. The "capitalist world-economy," as Braudel (1972) and Wallerstein (1974) implicitly recognize, does not *act upon* nature, so much as *develop through* nature-society relations (Moore 2003a, 2003b, 2011). The modern world-system is a capitalist *world-ecology*, bringing together the endless accumulation of capital and the production of nature in dialectical unity. From this perspective, historical capitalism signifies that messy bundle of relations between human and extra-human nature. For more than five centuries, capitalism has been at once a mighty subject project and objective process, aimed at subordinating this messy relation in pursuit of endless commodification.

The transformation of Potosí was a pivotal moment in the formation of this capitalist world-ecology. Potosí's contribution to system-wide monetary stocks is fairly clear. The New World accounted for 74 percent of the world's silver production in the sixteenth century (Barrett 1990: 225). By far the largest producer, Potosí's output dwarfed that of Zacatecas (Mexico) by a factor of seven (Garner 1988: 911). Almost overnight, Potosí emerged as a major world city.

With 160,000 residents in 1610, it was larger than Amsterdam (80,000), London (130,000), Sevilla and Venice (150,000) (Bakewell 1988: 191; Kamen 1971: 21). Together with the mercury mines of nearby Huancavelica, Potosí's silver complex pioneered a rapid expansion of commodity production throughout the Viceroyalty of Peru and the nascent world capitalist system, with profound implications for the health of land and labor alike.

The place of socio-ecological transformation in Potosí's silver revolution is, however, far from clear. There were, to be sure, many terrible environmental consequences of this revolution— deforestation, soil erosion, mercury poisoning, rising malnutrition, and so on. We encounter these in what follows, but to focus upon consequences is to miss the crucial point: *the production of nature is constitutive of capitalism*. The genius of early capitalism was to appropriate extra-human nature (resources, soil fertility, etc.) in the service of maximizing labor productivity. Appropriation, in this sense, refers to what Marx calls nature's "free gifts" (1967 III: 745). Conceptually, these free gifts comprise sources of potential wealth that are not produced through the circuit of capital (M-C-M'). This is the difference, for example, between an "old growth" forest and a tree plantation. Although these sources of wealth are commonly understood as extra-human, in fact the appropriation of *human* nature as surplus labor is a decisive and recurrent feature of historical capitalism, manifest in successive waves of depeasantization. This too is a central part of the story of Potosí's rise to world preeminence, as well as its subsequent decline.

From this perspective, the historiographical emphasis on "European" expansion in this era may be reinterpreted through an emphasis on *commodity frontiers*. Crucially, these commodity frontiers worked their way through European no less than American space. The spectrum of vital food, labor and resource sectors— comprising the production and extraction of sugar, silver, forest products, iron, copper, fish, flax, grain, slaves, and livestock— was characterized by a profoundly restless historical geography. In contrast to the centuries-long drift of regional primacy in premodern civilizations, these vital sectors were rapidly remade through successive frontier movements. In sugar, for example, one region after another quickly rose to world primacy (Madeira, São Tomé, Pernambuco, Bahia, Barbados, and onwards) only to see its competitive position erode, and new rivals climb to the top. The same pattern held for silver mining as well. Potosí's ascent was enabled by the crisis of Central European mining, the preeminent producer of the "first" sixteenth century; in time Potosí would yield its primacy to New Spain. The explanation for this pattern is straightforward. New commodity sectors moved to regions where the commodification of land and labor was low, and where indigenous capacities for effective resistance were minimal. There was, as a result, a bonanza of free gifts that could be easily appropriated. Sooner or later, however, the era of "windfall profits" (Webb 1964) comes to an end. Silver veins are depleted, trees are cut down, soil fertility exhausted, peasant formations undermined. Under the conditions of the time, this translated to declining labor productivity, and the region's competitive position with it.

This commodity frontier strategy affected two world-historical ruptures of signal importance after 1450. In the first instance ecological wealth from forests, fields, mines and laboring classes would be extracted in the quickest way possible. Waste and pollution was of little concern so long as it failed to enter the register of profitability. Second, the acceleration of socio-ecological contradictions within regional production complexes gave rise to recurrent movements of geographical expansion. The rapid movement of ecological overdraft with successive commodity frontiers undermined the socio-ecological conditions of production and therefore the conditions of profitability— *typically within 50 to 75 years in any given region*. These conditions were not simply biophysical; scarcities emerged through the intertwining of resistances from labouring classes, biophysical shifts, capital flows and market flux. Once the extraction of this regionally delimited ecological wealth faltered, this modern instantiation of the "metabolic rift" compelled the search for new commodity frontiers (Foster 2000; Moore 2000).

The commodity frontier therefore represented an epoch-making strategy of appropriation that was, at once, crisis-creating and crisis-fixing. The crisis of Central European silver mining was the first precondition of Potosí, as geographical site rather than geological find. The great wave of European silver mining had crested by the 1540's. The decline of Saxon and Bohemian silver mining was reinforced by the rise of Potosí; it was not a consequence of it (Moore 2007: chapter two). The crisis of Central Europe's mining complex was therefore an ecological crisis conceived relatively and relationally. *Relative*, not absolute, exhaustion was what really mattered, and this relative exhaustion was a product of the contradictory relations of markets, states, and social classes in Central Europe and the capitalist world-ecology. Large-scale mining did not disappear in Central Europe; its centrality was merely displaced through global expansion.

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Potosí's silver revolution, initial phase, 1545-68

The systemic re-centering of silver mining in the New World offered a near-perfect combination of favorable socio-ecological conditions: fabulously rich ore deposits and accessible sources of cheap labor power. If Europe's mining complex faced formidable obstacles at home, in the New World it could play a decisive role in fundamentally reshaping the hemisphere's socio-ecological order. By 1600, Europe's silver production amounted to just ten percent of the American gold and silver arriving in Seville, and this was only a portion (albeit a large one) of New World bullion exports (Brading and Cross 1972: 545).

The core of this hemispheric reconstruction was city-building, the pillar of Spain's colonial strategy. This approach, "the direct opposite of the British gradualistic model, permitted Spain to conquer and control an entire continent in a few years with a very small occupying force." The Spanish colonial city was the vanguard of imperial advance. "From it the Spaniards moved out to a hostile environment to conquer, control, and indoctrinate the surrounding populations. Conquerors lived, by and large, in the city, while the conquered remained in the countryside" (Portes 1977: 61).

On the mining frontier, this urban-imperial logic was carried to new heights. Dominant and dominated, mining boomtowns ruled over the surrounding countryside, even as they were subordinated to broader imperial and economic structures. They were the organizing centers not only of underdevelopment in the economic sense, but of a profoundly unequal ecological exchange between American peripheries and European cores, enabling a new, multi-layered and globalizing town-country antagonism. The mining frontier thereby created an increasingly serious rift in the metabolism between the country and the city—a "metabolic rift" (Foster 2000)—within Latin American regions, and at the scale of the world-economy. Nutrients flowed from country to city within the New World, and thence from urban centers in the periphery to the core. As relative exhaustion seized regional formations harnessed to the political ecology of the metabolic rift, successive waves of geographical expansion ensued. The competitive logic inscribed in the modern world market drives the exhaustion of local ecological wealth (including local sources of labor power). This necessitated the geographical expansion of commodity relations, either through the progressive extension of city-hinterland relations within regions, or the outright relocation of production.

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In the quarter-century following the 1545 discovery of silver on the Cerro Rico ("rich mountain"), the path from rock to pure silver was circuitous indeed. Mining and smelting remained largely under Indian control. Indians mined silver ore, much of which found its way into Spanish hands as tribute. These in-kind tributary payments were then sold back to the Indians, who smelted the ore in thousands of *guayras*, small wind-ovens specially designed for the high altitude. "It was a pleasant site in those days to see eight, ten, twelve or fifteen thousand of these Fires burning all at the same time" (Vega 1608: 347). Subsequently, the Spaniards acquired the pure silver through the market, where their purchasing power was augmented by control over the lucrative coca leaf trade (Cobb 1947: 117-99). But transaction costs remained high, or too high at any rate for the Spaniards' tastes. "These Indian workemen are riche," Augustin de Zárate commented at the height of the *guayra*- silver boom in the 1550's, "for but he that hathe but foure or five thousands poyzes [*pesos*], is counted but poore" (1555: 100).

The arrangement worked so long as ores remained rich. In the first two decades after Spain's enclosure of Potosí, the ores were rich indeed. In the earliest years, veins sometimes yielded ore with silver concentrations of 25 percent or even higher (Wilson and Petrov 1999:10; Ulloa 1772: 64). Mixed with relatively soft chlorargyrite, the silver was smelted in the small *guayras* with relative ease (Cieza de Leon 1553: 335-36).

Soon, however, ore quality declined sharply. Surface deposits were quickly mined out, rendering mine work more arduous and less remunerative for Indian workers. By the late 1560's, the yield on Potosí ore fell 98 percent from two decades earlier (Cobb 1947:124). Declining yield implied rising fuel inputs, the major production cost for smelter. Once nearby woodlands were decimated for charcoal production and Indian smelters turned to *ichu* grass. When dried, *ichu* made for an acceptable, if inferior, substitute. Silver output fell two-thirds between 1546 and 1571 (Bakewell 1987: 239). Indian workers began to flee mine work in droves. By 1561, 20,000 Indians lived in Potosí but just 300 worked the mines, 94 percent fewer than a decade before (Cole 1985: 4). The first phase of Peru's silver revolution had come to an end.

Prelude to ecological revolution: Spain's fiscal and agrarian crises

The dramatic contraction of Potosí's silver exports to Spain was a matter of some significance. Philip II's permanent war strategy weighed heavily on the domestic economy that, by the 1560's, was experiencing deindustrialization and agro-ecological stagnation or worse. Philip may have taken too seriously the motto he emblazoned upon Potosí's second coat of arms: "for the wise King this lofty mountain of silver could conquer the whole world" (quoted in Rudolph 1936: 536). The contraction of silver production was quickly followed by two developments. First, Spain's military spending increased sharply after 1566 (Parker 1974: 561). Second, Castile was gripped by a series of fiscal crunches. Philip II tripled taxes and thrice declared "bankruptcy"— in reality converting short-term into long-term debt by issuing the bonds known as *juros*— between 1557 and 1577 (Parker 1974: 568-69; DuPlessis 1997: 50-3). The very bankruptcy that precipitated the 1557 European crisis, visiting ferocious devaluation upon South German capital, was made possible by the flood of American silver pouring into Sevilla in the early 1550's. Philip was no longer beholden to the Fuggers and could dispense with their services.

A fundamental source of Philip's fiscal problems was the stagnation, and eventually retrogression, of Castile's agro-ecological regime. These problems mounted in the closing decades of the sixteenth century (Moore 2010a). Although Spain's agrarian crisis in the second sixteenth century is well known, its political ecology has been underplayed. A 1609 source underscores the agro-ecological moment: "The insatiable farmers were exhausting the fields" (quoted in da Silva 1964: 244). This was almost certainly connected to the peasantry's escalating indebtedness. There was a "heavy increase in the mortgages on peasant property" by the early seventeenth century (de Maddalena 1974: 299). Between 1570 and 1630, "little by little, almost everywhere people [in Castile] became obsessively worried that the land could be exhausted." Growing concerns over "decrease in yield" and the "search for new lands" were, da Silva argues, "*actually parallel*" (da Silva 1964: 244, emphasis added; also Elliot 1963: 115).

This internal frontier movement instantiated, on a regional scale, the systemic dimensions of the commodity frontier discussed earlier. The regional contradictions could be eased, for a time, by grain imports. But grain imports were financed with American silver, primarily from Potosí. Reliable grain supplies therefore demanded a steady silver inflow from across the Atlantic. So long as the expansion of arable land sustained a rising domestic population, the inhibiting impact on the Castilian "home market" was limited. But the expansion of arable land was, it turned out, insufficient. For Braudel, "the reclaimed land often gave an inferior yield" (1972: 426). Weisser sees a "severe downturn" in yields in Toledo and Segovia between 1600 and 1640 (1982: 153). Even a modest decline in yields, say from 1:4 to 1:3.5, represented a dangerous contraction in agriculture's capacity to feed the extra-agricultural population (Parker 1979: 39). Once population growth stagnated and a great reversal was set in motion— Braudel calls this Mediterranean-wide movement "an agricultural revolution in reverse" (1972: 427)— escalating tax burdens throttled the direct producers. There was, then, a decisive agro-ecological moment to Spain's fiscal difficulties.

This is not to deny that American silver raised production costs for Castile, or that Dutch manufacturing prowess allowed its textiles to penetrate the Castilian market (Moore 2010a). The question is one of relative causal weight in which the political ecology of the situation remains salient. Segovia's thriving textile industry (second only to Cordoba's) virtually collapsed in this period, its output falling three-quarters between 1570 and 1600 (Kriedte 1983: 73). Was this not related to the agro-ecological retrogression and the escalation of tax burdens that ensued? Between 1559 and 1598 "the burden on the ordinary taxpayer in Castile increased by some 430 [percent], at a time when nominal wages had risen by only 80 percent" (Kamen 1994: 486). The collapse of the home market and stagnating agricultural productivity— already amongst the lowest in Europe (Kamen 1994: 487)— meant that Philip II's geopolitical projects could be sustained only through reckless borrowing and imperial restructuring abroad. Taxes on the peasantry could be ramped up, but only so far and no further. When Charles V abdicated in 1556, the Crown's "*juro* debt ... or annuity payments on loans made largely for the war effort," amounted to 68 percent of "normal Castilian revenue" (Kamen 1994: 481). By the time of Philip's death in 1598, *juro* debt was eight times the Crown's annual revenue. This debt relied on Potosí's silver production. Precisely who owned the debt? The Genoese above all, and it was Genoese capital that financed commodity production throughout Europe (Braudel 1972: 501-2; 1984: 157-74, 208-9).

The creation of the public debt, as Marx notes, was a decisive moment of primitive accumulation (1977: 915). This was not only because the *juros* accumulated by Genoese bankers were tradable, and this power granted the

Italians unusual freedom after 1566 to export silver directly from the Peninsula. It was also because the Genoese had reoriented their "surplus capital" from the American trade towards the bond market, thereby opening the door for Dutch capital. The financial expansion launched by the Genoese in the aftermath of the 1557 crisis was a moment of stagnation *and* expansion of the material economy. (The world-historical alchemy of *combined* and uneven development.) We might observe that this duality was carried forth by a geographical division, indeed one that would persist into the twentieth century. The rapid expansion of the productive economy in the north after 1557 rested upon the financial power of the Genoese in the south, whose surplus capital was now available not only to fund wars, but also a new system-wide expansion centered in northern Europe (Arrighi 1994; Moore 2010b).

The rise of the Dutch was, then, intimately connected with the decline of the Spanish. And it was this conflict that underpinned the implantation of an increasingly capitalist ecological regime in the Andes. This brings us back to the trans-Atlantic environmental history of Castile and Peru. Castile's credit-worthiness turned on its revenues from the silver mining frontier. These revenues could be sustained only by a constant effort to intensify and expand the imperial division of labor— one that for all its premodern vestiges ultimately lived and died on the production of a handful of strategic commodities (silver above all.) And this was possible only through recurrent waves of environmental transformation driven by the competitive logic of a polycentric geopolitics and the modern world market.

If the ecological specificities differed between Castile and Peru, the tendencies towards what Sauer (1981) once called ecological "overdraft" and what Marx (1977) would call primitive accumulation were in full force: soil exhaustion and thence the restless search for new arable land, monetization, proletarianization (or more properly, semi-proletarianization), land concentration. Crudely put, the political ecology of change in the metropolis is dialectically bound to the political ecology of change in the colonies. This town-country or metropolitan-colonial "feedback" moment of modern environmental history is one issue that remains largely untouched. And so it is from this very perspective, not simply world-historical and regional but one that pivots simultaneously on the construction and contradictions of the town-country and metropolitan-colonial divisions of labor, that we trace the interrelations between Castilian and Peruvian environmental history at the end of the sixteenth century.

From plunder to production: colonialism as socio-ecological project

By 1568, Spanish power faced a conjuncture of regional crises: 1) the collapse of *guayra*-based silver production in Peru; 2) escalating resistance to Spanish authority in the northern Netherlands; and 3) the progressive dilapidation of Castile's agro-industrial base. The most manageable of these crises was the situation in Potosí. When the Crown convened a special junta in 1568, the new Viceroy's charge was to impose a far-reaching transformation of Peru (Mumford 2004). The new Viceroy, Francisco de Toledo, confronted two basic, and tightly connected, socio-ecological challenges. The first was the technical challenge posed by the rising labor and fuel demands of *guayra* silver production. The second challenge was labor mobilization in the wake of massive worker flight from the mining sector during the 1560's.

Arriving in 1569, Toledo immediately organized a *visita* to survey the Viceroyalty. The question of labor was central. The Potosí *mita* was proclaimed in 1572, establishing a large-scale system of forced labor drafts. Three million Andeans would work in the mines before the abolition of the *mita* in 1819 (Ferry 2000). This kept labor costs low in the face of the rising labor demands of pit mining. The *mita*'s timing was surely influenced by the successful adaptation of mercury amalgamation technology, used in New Spain from the mid-1550's, to Andean conditions. By pulverizing lower-grade ore into dust and mixing it with mercury in large stone tanks, the silver and mercury bonded and could be readily extracted. Fuel and transaction costs were minimized, and overall output maximized. Toledo's third major innovation was the construction of a "pharaonic" hydraulic infrastructure, commenced in 1573, that would eventually contain 32 lakes covering 65 km^2 (Gioda et al. 1998; Craig 1993). This hydraulic infrastructure supplied power for the grinding mills.

These three socio-ecological innovations bore fruit quickly. Potosí's silver output increased nearly 600 percent between 1575 and 1590 (Bakewell 1987: 242). They were at the core of a series of transformations implicated in the rapid commodification of land and labor throughout Peru, and in the region's deepening articulation with a globalizing capitalist system.

At the point of production, control passed from Indian to European hands. The colonial transition replayed on an expanded scale the transition from small-scale artisanal mining to large-scale industrial extraction in Central Europe a century before (Lynch 2002). Spanish mine owners were in the midst of "evolv[ing] from low-investment, low-risk [entrepreneurs] into industrial businessmen" (Cole 1985: 18). The *guayras* were displaced, although not eliminated. Even at the height of Potosí's glory in the early seventeenth century, these small wind-ovens persisted (Espinosa 1628: 623).[2] After 1571, in the place of the *guayras*, there were now huge stone tanks, capable of holding two and a half tons of crushed ore (Bakewell 1987: 214).

The immediate process of silver production was directly implicated in the Fuel Question. It seems that everything in early capitalism came back to the forest, or "forest-equivalents" as in Dutch peat bogs or, as well shall see, the tough, coarse *ichu* grasses of the Andes (Moore 2010a, 2010b). In contrast to the era of fossil fuel capitalism that began in the early nineteenth century, the greatest crisis tendency of early capitalism was not overproduction (too few customers) but *under*production (too costly energy and raw materials) (Moore 2011). The transition to mercury amalgamation was, therefore, especially important because it reduced per unit fuel costs. Yet, because amalgamation enabled such a large increase in output over so short a time, the consequence was *more*, not less deforestation.

The quantum leap in the scale of production after 1571 implied a quantum leap in the consumption of human and extra-human nature. The extraction of mercury itself demanded a considerable volume of charcoal, resulting in deforestation around the mercury mines at Almaden (Spain) and Huancavelica (Peru) (Parsons 1962: 200-1; Brown 2000: 467; Favre 1975). At Potosí, moreover, the amalgamation process demanded fuel at nearly every step. Ore had to be roasted prior to crushing. Once amalgamated, the resulting spongy mass of mercury and silver was heated again in clay pots. The pure silver was then reheated and fashioned into ingots, only to be subject to still more "hot flame[s]" in the assaying process (Espinosa 1628: 626–8). The energy requirements took up a sizeable share of the workforce. By 1603, when we find "growing scarcity and cost of fuel" around Potosí (Bakewell 1987: 214), 3,000 workers were engaged in the wood and fuel trades. This compared to 4,600 working underground in the mines (Anonymous 1603: 122). And the number of workers in the wood and fuel trades refers only to those observed *in* Potosí; in seventeenth century Europe the rule of thumb was "five forest workers and haulers for every worker" at the smelter (Sundberg 1991: 9).

The shift from the "hot" technology of smelting to "cold" mercury amalgamation did not eliminate the problem of fuel supply. On the one hand, a kilogram of silver could now be produced with considerably less fuel than previously. How much less? In the 1780's, the "improved amalgamation process" pioneered by the Austrian metallurgist von Born consumed just 15 percent of the fuel demanded by European silver smelters (von Born 1791; Whitaker 1941: 67; Teich 1975: 326). This new method, which enjoyed success at Idrija, reduced by half the fuel budgets of the older, Almaden-style furnaces (Whitaker 1941: 69). At best, then, sixteenth century amalgamation required 20-30 percent of the fuel consumed by smelters. The lower figure was possible only with high-grade ores, which were exhausted by 1590. In practice, my estimation is a fuel efficiency advantage for amalgamation of not more than 60 percent for the period 1571-1650.

Even so, a 60-70 percent increase in fuel efficiency was significant. But rising fuel efficiency, as Jevons suggests (1906), does not translate directly into reduced demand. Often, rising input efficiencies leads to rising aggregate consumption. Insofar as rising fuel efficiency is achieved through technological innovations in the capitalist market, such efficiency translates axiomatically into rising demand for raw materials. This is the "Jevons Paradox" (Clark and Foster 2001). Although associated most closely with nineteenth-century industrialization, the paradox was clearly in play during Peru's long seventeenth century. Upon introduction of the amalgamation process, output grew so fast that gains in fuel efficiency were offset by the greater than seven-fold increase in silver production between 1572 (120,000 marks) and 1585 (860,000 marks) (Bakewell 1988: 16-7). Assuming a 60 percent savings in fuel consumption per mark, total fuel consumption tripled.

Even this may understate the increase. The transition to mercury amalgamation was never total. The *guayras* did not disappear. Indian-controlled production had been displaced from its centrality in production. But it was not eliminated by amalgamation. On top of this, ores with high lead content were "not proper to be separated by Quicksilver." Thus the mines at nearby Andaçaba, not more than 25 miles from Potosí, were barely profitable because "there is not enough wood near the place to melt it down" (Barba 1640: 133).

The fruits of the Jevons Paradox were therefore short lived. As early as 1580, Capoche reports on the "excessive price of wood, in relation to the cost of everything else" around Huancavelica, to which timber was brought in from a distance of 25-30 leagues (1585: 117). By the 1650's, mercury production was entirely dependent upon *ichu* as no wood was available (at a reasonable price) close to Huancavelica (Cobo 1653: 150; Wise and Féraud 2005). A century later in 1763, Governor Ulloa reported that accessible *ichu* supplies around the mercury center "had been exhausted." The grasses were trucked in from 15-20 miles away, "with a consequent increase in its cost" (Whitaker 1941: 123). Indeed, fuel supplies were so exhausted that it was impossible to introduce the more efficient Idrija furnaces that depended on charcoal but could not run effectively with *ichu*.

If *ichu* could substitute for charcoal, construction timber remained indispensable. As mine shafts plunged ever deeper into the earth, the demand for quality construction timber grew geometrically. Potosí's mines were, in effect, a vast subterranean forest, and one that had to be replaced, every six years on average (Westermann 1996: 930). Nor was this the end of the demand for timber. The wooden axles for the grinding mills (*ingenios*) were imported from Andean valleys far below, sometimes as distant as 200 miles away (Bakewell 1987: 218; Sauer 1981: 50).

Construction and fuel needs devoured the forests around Potosí, driving successive expansions of the timber hinterland. Each expansionary movement exerted upward pressure on production costs. By 1714, Potosí, even as its population had declined from 160,000 to 70,000 and its mills declined from 120 to just 40, was drawing timber from Paraguay (Frezier 1717: 83, 145-46; Espinosa 1628: 624).

Moving from the point of production to the social division of labor, we can see two distinct and mutually reinforcing pressures. Potosí had ballooned to 160,000 residents in the first half of the seventeenth century (Hanke 1956). Beyond the demands of production, there was relentless cold: between May and August "you can hardly sprinkle your house before it freezes" (Espinosa 1628: 632). Madrid, of roughly comparable size but enjoying a warmer climate, consumed some 12,500 tons of charcoal each year for heating and cooking in 1630 (de Vries 1976: 164). And while the city's semi-proletariat may have used other fuel sources, various grasses and dung, it seems a safe estimate that fuel consumption outside the extractive sector must have been at least twice that of Madrid's. (Never mind the additional demand for construction timber!)

But neither demography nor climate determined rising fuel consumption, although these were important. It was the wood-intensive character of European world-economy— "a civilization literally made of wood," Sale wryly observes (1990: 84). Silver amplified these demands by an order of magnitude. Even in warm breadbasket regions such as Cochabamba, whose farms supplied Potosí, Spanish colonials consumed wood at a feverish pace. The contrast with their indigenous neighbors was striking. The Jesuit Bernabe Cobo observed that the Indians "use so little [wood] that a Spanish household burns more wood in a day than an Indian household does in a month." The difference, Cobo argued, was to be found in the industrial accoutrements of European civilization. The Indians "barely had any other reason to use wood ... [T]hey did not have ovens for bread, nor lime and bricks nor the other things for which we consume so much firewood." In contrast to the Europeans, "*they did not need to cut down the thick trees*" (1653: 236).

Deforestation weighed particularly heavily on mountain ecosystems, which suffer from high rates of soil erosion and enjoy only a "fragile stability, easily upset by unintentional human action" (McNeill 1992: 352). By 1603, the devastating consequences of the Cerro Rico were readily visible:

> Even though today, *because of all the work done on the mountain,* there is no sign that it had ever had a forest, when it was discovered it was fully covered with trees they call *quínoa,* whose wood they used to build the first houses of this settlement ... On this mountain, there was also a great amount of hunting of *vicuñas*, *guanacos* and *viscachas*, animals very similar to the rabbits of Spain in their fur and meat, but with a long tail. There were also deer, and today not even weeds grow on the mountain, not even in the most fertile soils where trees could have grown. This is the most frightening, because now the mountain is covered with loose gravel, with little or no fertile land, crossed with sterile mineralized outcroppings (Anonymous 1603: 114-15, emphasis added).[3]

Did this lead to serious erosion problems, and therefore undermine the socio-biological structures of the emergent Andean peasantry, which would in turn have undermined the reproduction of low-cost labor power for the mines? Our anonymous reporter from 1603 suggests so. Part of the answer to this question must wait until we move to the reorganization of human nature in Peru's silver revolution. Iberian expansion in the New World everywhere led to the massive introduction of European livestock, and this broadly favored erosion (Melville 1994). Frezier observed after nearly two centuries of conquest in Peru that the roads traveled by gigantic mule trains, "scarce ever [have] any Grass" (1717: 175). These gigantic mule trains were far from incidental. Silver mining centers, along with sugar plantations, were the greatest consumers of Eurasian animals in the New World (Moore 2007). And these animals were implicated in widespread deforestation throughout the Andean highlands:

> Under natural conditions a large part of the Andean highlands would be covered with forests or woodlands ... [T]he west Andean valleys ... would be clothed in woodland if man had not interfered for hundreds or thousands of years. As in the more human and cooler altiplano, these woodlands were destroyed partly by cutting firewood and timber and by burning adjacent grassland areas during the dry season, but mainly by the browsing of indigenous as well as introduced animals ... [With the introduction of Eurasian animals] *overgrazing and acceleration of soil erosion soon became severe problems*, simply as a result of intensifying and diversifying the impact on the land. Animal-trampling on the slopes became more dangerous, because llamas and alpacas have broader and softer feet than the sharp-hoofed sheep, goats, cattle, donkeys and horses which replaced them (Ellenberg 1979: 407, 411, emphasis added).

As for indigenous livestock, llamas especially were widely used to supply Potosí. In this respect there was continuity. Under Incan and Spanish hegemony alike, llama herding was organized under local control; this a key difference between stockraising frontiers in Peru and New Spain (Simpson 1952). The historical-geographical literature has tended to emphasize rising *human* population as more or less correspondent with rising *animal* population (e.g., Dore 2000). But this obscures a significant unevenness between the two. A defining feature of European imperialism from the beginning was the rapid expansion of Eurasian livestock. These animals multiplied out of all proportion to their human companions. This was, as Crosby suggests (1986), partly a matter of finding new environments with few natural enemies. It was the inevitable accompaniment to the animal-intensive character of the capitalist world-ecology in long sixteenth century. Marx's astute if undeveloped observation that "every particular historical mode of production has its own special laws of population" applies to extra-human as well as human populations in the modern world-system (1977: 784).

Large-scale mining was inconceivable without abundant livestock. Extractive centers relied on these mammals not only for food, but also for transportation, hides for sacks, pouches, ladders, ropes, shoes and clothing. Not to mention as organic motors for the *ingenios*, mine hoists, and other machinery; as sources of power, the stronger Eurasian animals were indispensable. Animal fats provided the oils to lubricate machinery and for tallow to make candles. Underground mining was impossible without these (Espinosa 1628: 625). Consumption of tallow in 1730's Zacatecas— considerably smaller than Potosí— was over 80 tons *a year* (Semo 1993: 12; Crosby 1972: 86; de France 2003: 107). Espinosa was moved to characterize the 300,000 pesos spent annually on candles in Potosí as "almost unbelievable" (1628: 625).

Moreover, while colonials could have chosen to eat llamas and alpacas, Iberian tastes favored those Eurasian animals with sharp hooves (de France 2003: 117-22). The consequent inflow of *live* animals into Potosí was staggering. Our 1603 informant reports on 1,000 sheep entering Potosí weekly, another 2,000 llamas, and each year, 4,000 cattle for the slaughterhouses, suggesting many more cattle "equivalents" in terms of leather bags, rope, clothing and shoes, tallow, and so forth (Anonymous 1603: 127; also Espinosa 1628: 517-18).

In Espinosa's account, one can hardly skip a page without missing a reference to ranching in Peru. In one region nearby Potosí in 1610, he marveled at the fourteen ranches, with 1,600 cattle, 5,000 sheep, 12,000 goats, and 400 brood mares. "At present [1616] there are many more, for they breed well and multiply rapidly." In another region Espinosa observed an "annual increase of 18,000 head" in the cattle, sheep, and hog ranches (1628: 530, 536).

Even these figures do not convey the immensity of Potosí's animal consumption. The *mita*, which we will discuss momentarily, put some 13,300 workers on the roads to Potosí every year. With their accompanying families, there were 50-60,000 people heading to Potosí in these annual labor migrations. And they had friends. Some 40,000 llamas made possible these migrations, which in some cases covered hundreds of miles (Cobb 1947: 80).

Nor were dietary tastes and the *mita* alone responsible for the livestock explosion. The extractive consumption of animal labor power was also a factor. Here we can consider, in Hribal's memorable phrase, how "animals are part of the working class" (2003). Daily, some 8,000 llamas carried ore from the Cerro Rico to Potosí's *ingenios* (Espinosa 1628: 625). In the early eighteenth century, Frezier estimates that 80-100,000 mules were brought in from Tucuman and Chile, simply "to make good ... continual Loss." The roads to Potosí were "better known by ... the Skeletons of those that tire out" than by the marks of hooves (1717: 175).

Llama mortality was even higher. This stemmed partly from a challenging geography. Llamas, less hardy than expensive mules, often expired in the arid journey from the mercury entrepôt at the port of Arica to Potosí. They also suffered when the sheepskin mercury bags burst, a common occurrence. Moreover, at least a partial transition from llama- to mule-trains was underway in the early seventeenth century. This would have been more costly but also a sure way of recouping one's investment in timely fashion. Was this related to escalating pressures to accelerate turnover time? The organizers of these trains were merchants, who in contrast to the *azogueros* enjoyed no protections against wholesale foreclosure. Merchandise could be seized; productive capital could not. Mule trains cut transport time by a third or more relative to llamas, but the animals "suffered badly from the speed and the lack of food on the journey." Why was food lacking? This was partly because maize was costly and heavy and partly because "there was little pasture" (Cobb 1949: 40, 37, 40-1, 41). Pastures on the road to Potosí had been overgrazed. Could we expect anything else with a stunning 350,000 llamas supplying Potosí every year (Browman 1974: 194)?

The upshot is that non-human populations were rapidly increasing and becoming "urbanized." That is, Peru's transition to capitalism necessarily entailed an unprecedented geographical concentration of human *and* non-human animals.

Mobilizing bodies: Potosí and the human natures of underdevelopment

If Philip II was frustrated in his European ambitions, the conquest of Peru proceeded with unprecedented modernity and success. The decisive pivot was Potosí, but not simply because it produced silver. The geographical concentration of silver ore in the Cerro Rico— in contrast to New Spain's polycentric mining frontier— enabled and encouraged a radically interventionist imperial policy. Such policies would have borne little fruit if not for the social and physical infrastructures of the Incas. The *mita* was the most conspicuous reinvention, as colonial practice transformed the premodern labor draft system into a dragnet of primitive accumulation. The *mita* was at once a relation between people and a relation with nature. It was a spatial strategy that created and depended upon an impressive built environment of roads, bridges, and inns. These infrastructures, retooled and redirected after 1531 in the interests of capital accumulation and tribute extraction, "allowed Spaniards to dominate Andean space to a degree not yet possible ... in the tamer, more regular spaces of Iberia" (Mumford 2004: 319).

The course of events in Potosí captures what seems to be the basic socio-ecological pattern of metallurgical commodity frontiers in the early modern period. In the early stages, high yielding ores translate into high wages and decent working conditions. But sooner or later ore quality declines. When this happens, profitability begins to hinge more and more on two things: 1) rising capital intensity, manifest not only in surface infrastructures but also deeper mines; and 2) driving down the wage bill for labor power. While technological and social innovations could temporarily check rising costs, they could not do so indefinitely.

Early capitalism was biased towards the second option, the external ecological fix, although as we have seen, technological innovation was certainly operative. Drawing workers either from zones outside the commodity economy, or only loosely articulated with it, mine owners found themselves in a favorable position not only to enjoy the fruits of cheap labor, but also to exploit these workers with little regard for their health (Tandeter 1981: 104). In itself, the death and bodily damage suffered by Indian mineworkers, much like mortality in the slave trade, posed no real *short-run* threat to profitability in the early modern world-economy. In certain respects, the "brutal relationship" of the Indian laborers, known as *mitayos*, and the colonial entrepreneur was even more exploitative and dangerous than under slavery (Stern 1982: 84).

The contrast with Incaic mining practices was especially sharp. Under the Incas, rest periods had been common; "the same Indians were not continuously in the mines ... *and none of them died from overwork*" (Cieza de Leon 1553: 163, emphasis added). Under the Spanish, this changed radically. The problem was not simply that the colonial *mita* was exploitative, which it surely was. Rather, the mode of organizing labor through coercive, but short-run, labor drafts intensified the exploitation of the *mitayo*, perhaps even beyond that of African slaves. In this sense, the colonial *mita* prefigured indentured servitude in seventeenth-century British possessions (Williams 1944). The essence of the problem was that the *mita* "did not place any investment at risk. ... Immediate profitability was the overriding consideration of the entrepreneur in his relation with the forced laborers." (Tandeter 1981: 104) By the end of the sixteenth century, at the height of Potosí's silver revolution, this tendency was amplified by the practice of hiring out *mitayos*. Such overexploitation represented not only a shameful legacy of early European expansion, but also constituted a major force for geographical expansion, within Peru as well as outside it.

Potosí's renaissance after 1571 was driven initially by the exploitation of tailings, ore that resisted the *guayras*. But these were exhausted by the end of the decade. The great advantage of the new amalgamation technique was its capacity to extract silver from low-grade ores, and this led to a plunge into the earth. A rising proportion of *mitayos* was put to work in the increasingly deeper, and increasingly dangerous, mines. Work-related fatalities escalated sharply. "As the mines plunged deeper into the Cerro, the work grew harder and accidents became more common. *Mitayos* were buried in cave-ins, suffered broken limbs in falls, and succumbed to respiratory diseases" (Cole 1985: 23-4).

Constructing these deeper shafts, along with the gruesome depreciation of labor power, reduced labor productivity and therefore increased production costs, *all things being equal*. But for the mine owners, there was a temporary fix. Owners began to disregard colonial prohibitions and to impose production quotas. This was early capitalism's "stretch out," as the bosses dramatically extended the working day. In the 1570's, the colonial state forbade more than two trips a day for *apiris*, workers who carried the ore from the mine depths to the surface. By the 1580's they were carrying as many as two *dozen* loads of 25 kilograms upwards some 300 meters. Mine shafts often flooded, forcing *mitayos* to work "knee-deep in water," rendering them susceptible to disease. Rest periods—originally two weeks for each one worked—were increasingly disregarded (Cole 1985: 23-5; Tandeter 1981: 104-5; Cobb 1947: 86-9). By 1600, "the proprietors decided they were losing time changing shifts, so they started keeping the workmen underground continuously from Monday evening to Saturday" (Rowe 1957: 174). The mines, said mine owner Luis Capoche, became a "harsh executioner of Indians, for each day it consumes and destroys them, and their lives are made miserable by the fear of death" (in Bakewell 1984: 145). Notwithstanding this increasingly brutal labor regime, yields continued to decline. By the mid-1580's, "workers were taking out only half the amount formerly produced" (Cobb 1947: 77).

For the workers on the surface who crushed the ore in the *ingenios*, conditions were no better. Inhaling dust, these workers contracted silicosis, rendering them vulnerable to a wide range of respiratory diseases (Bakewell 1984: 149). Once the ore was crushed into fine powder, it was mixed with mercury in the unhealthiest manner imaginable. "Instead of a hook to stir," Frezier wrote in 1714, "an Indian stirs it with his feet, to dissolve it" (1717: 157). The inhospitable climate reinforced and rendered all the more deadly the assault on workers' immune systems (Newson 1985: 55). Nor did it help matters that the standard work shift was 12 hours, day and night. This gave way to round-the-clock shifts during the rainy season, "when advantage had to be taken of every hour of adequate water flow" to power the *ingenios* (Bakewell 1984: 152).

These contradictions extended well beyond Potosí. Huancavelica was the mercurial pivot on which Peru's silver economy turned. Huancavelica's mercury mines— known far and wide as the *mina de la muerte* (mine of death)— were especially lethal. Mercury poisoning, ravaging kidneys and the central nervous system, complemented the standard occupational hazards. One estimate puts the life expectancy of the miners at Huancavelica at just six months (Goldwater 1972: 47), although Brown indicates that recovery from metallic mercury contamination[4] was possible (2000). Here as elsewhere, workers suffered from silicosis and tuberculosis. Mercury-laced dust amplified the problem. "Workers remained at the mines through the week and had little opportunity to wash away the contaminating dust. This prolonged their contact with the mercury and increased its absorption by their bodies." Nor was this the end of it. Poisoned workers carried the toxins from the productive to the reproductive sphere. Returning home, they "polluted the living quarters and contaminated their wives and children" (Brown 2000: 478).

Huancavelica's workers were in much the same position as those in Potosí. Between 1570 and 1630, high-grade deposits were exhausted. The exhaustion of ores led quickly to the exhaustion of the workers. Declining yields reduced some dangers but created new ones. There was less mercury in the dust, but drilling deeper pushed ambient temperature upwards. "Subterranean heat and poor ventilation within the galleries caused mercury to volatilize, converting "the atmosphere ... into a true 'culture' of mercury intoxication" (Brown 2000: 472). The workers had gone from the frying pan into the fire, and it was the profound danger of these fumes that most alarmed contemporaries (e.g., Acosta 1590: 242). To make matters worse, "catastrophic" tunnel collapses, surely related to rising timber costs, were a regular occurrence; fatalities of 500 were not unusual (Wise and Féraud 2005). As yields declined, the city's mining guild began to disregard the colonial state's regulations. Huancavelica's "naturally toxic conditions" were correspondingly magnified by the guild's profit-maximizing orientation (Brown 2000: 495). Small surprise, then, that by "1600 the environment at the mines had deteriorated to such an extent that conditions for the workers were horrific" (Brown 2000: 470-1; also Fox 1962; Stern 1982: 85). As many as *two-thirds* of Huancavelica's mineworkers died from their labor in the early seventeenth century (Brown 2000: 492).

Nor was mercury toxicity limited to Huancavelica. Given the constant movement of Indian laborers in and out of mining centers, widespread mercury deployment undermined the biological conditions for reproduction. Mercury contamination, Brown speculates, may have

> hampered recovery from the post-Conquest Andean demographic collapse not only due to the deaths at the mines but also because mercury poisoning made survivors less given to procreation. Mercury contamination can also diminish female fertility, a consequence that would have affected wives of *mitayos* living in quicksilver-producing huts or helping at the refining ovens (2000: 488).

The poisoning of bodies was complemented by the poisoning of land and water, and through biomethylation, back to bodies. The volume of mercury "lost" in Peruvian silver production was measured not in thousands but rather *hundreds of millions* of grams— some 300 tons *annually* between 1580 and 1640. Over half this volume evaporated or found its way into the oceans (Nriagu 1994: 174).[5] Nevertheless a huge volume remained, and this represented a powerful toxic invasion of regional ecologies (Cooke et al. 2009). Sixteenth century sources indicate that "the most moderate loss of mercury is about a pound for every mark [8 oz.] of silver refined, *a loss that can never be recovered*" (Gomez de Cervantes 1599: 151).

This was an early instance of capitalism's metabolic rift radically extended. Mercury not only disrupted the nutrient cycle; it poisoned it. Dumped into rivers, mercury poisoned the entire food chain: the fish, the animals who fed on them, and the humans who ate both. The bioaccumulation and consequent magnification of mercury toxicity through biomethylation— "concentrations of mercury in predatory fish can be a *million times* higher than in the surrounding water" (Stephens 2001: 20)— are not only highly durable over time. Mercury moves easily and rapidly through space, traveling and depositing in high concentrations hundreds of kilometers (Cooke et al. 2009).

Mobilizing space: *reducciones* and the "urbanization of the countryside"

The contradictions that flowed from the point of production intertwined with broader layers of the social economy. The late sixteenth-century silver boom presupposed a radical recomposition of Peru's biophysical wealth and its socio-spatial division of labor. This restructuring favored the maximization of production in Potosí, and the progressive commodification of internal and external nature (land and labor) throughout the region. All of Peru was to be at the service of Potosí (Vega 1608; Espinosa 1628).

Labor recruitment was the colonial state's great concern, and the pivot on which the region's new town-country division of labor turned. Needless to say, the Indians were not in a hurry to work for the Spaniards. The solution was found in the *mita*, a rotating annual labor draft. An institution rooted in the Incan empire, the Spaniards reinvented the *mita* to serve thoroughly modern ends. Imposed in 1572, the colonial *mita* conscripted one in seven adult males for work in the mines, textile workshops, "and any other task ... deemed worthy of the state's patrimony" (Stern 1982: 82). While there were many *mitas*, Potosí's was the largest and most expansive. In the 1570's, the annual draft mobilized some 13,500 workers, drawn from a region that stretched some 800 miles north to south and as much as 250 miles east to west (Bakewell 1987: 222).

This large-scale mobilization of bodies was premised on the large-scale reorganization of space. The *mita's* immediate precondition was the Empire's reorganization of village life throughout the Andes. Beginning in 1567 and accelerating after Viceroy Toledo's arrival in 1569, the colonial state initiated the "wholesale resettlement of the native population"— perhaps as many as 1.5 million people, roughly the population of contemporary Portugal— into "Spanish-style towns" (Rowe 1957: 156). Replicating on a grander scale the peasant settlements of *Reconquista* Iberia, these new "agro-towns" instantiated the urban primacy of Spanish colonialism: "[The] towns, not the countrysides, controlled and directed agriculture" (Gade 1992: 472). Here was an early glimpse into Marx's "urbanisation of countryside" (1973: 479).

These nucleated villages (*reducciones*) effected three major socio-ecological transformations. First, the concentration of Indians into densely populated encampments provided fertile epidemiological terrain for Eurasian diseases (Andrien 2001: 57). Second, large-scale resettlement typically entailed the removal of Indians from lands prized by Spanish colonials. Often relocated to inferior lands, the new Indian settlements were plagued by "high water table[s], problems of salination, and fog and cloud cover that effectively reduced the growing season" (Ramirez 1987: 598). Third, perhaps most fundamentally, the *reducciones* represented a serious challenge to the region's actually existing political ecology. Prior to European conquest, Andean settlement and landowning was premised on the principle of "verticality." The core strategy involved "working as many different microenvironments as possible" in order to ensure foods security and safeguard community (Stern 1982: 5). Potato cultivation in the highlands, for instance, was nourished by fertilizer (guano) supplied by coastal communities, which in turn consumed highland foodstuffs (Larson 1988: 19-20; Murra 1984; Godoy 1991: 400). Throughout the Andes, there evolved a "synchronized [pattern of] ecological relationships between coast, piedmont, highland, and puna," constituting "a finely calibrated system of food transfers" (Wolf 1982: 59).

Verticality may have been ecologically sound, but it was hardly conducive to the demands of the silver revolution. Such finely calibrated transfers, governed by relations of tribute and reciprocity, would have to give way to the cash nexus. The *reducciones* were therefore established on a mono-zonal rather than multi-zonal basis, eliminating "agricultural outliers in a variety of ecozones." For Gade and Escobar, the ensuing "decline in self-sufficiency" was an "unintended consequence of the Spanish-imposed system rather than a goal" (1982: 434). But this line of reasoning seems confused. Notwithstanding the intentions of specific actors, the Spanish-imposed system was premised from the very beginning on colonial hegemony over the "intense and wide circulation of indigenous commodities" such as coca, maize, and textiles (Larson 1988: 46).

> The intensity of commercial demand for food crops and special items like coca prompted many Indians to redirect the flow of goods and labor outward, toward the mining town. The shift in the balance between agrarian production for subsistence and for commercial exchange frequently had drastic consequences for the well-being of the social whole. ... [E]ven the highland peoples on their 'sterile lands' could not escape the incursion of commercial capitalism ... as long as colonial policies eroded

> the basis of 'social insurance' that traditional had buffered Andean communities from subsistence crises (Larson 1988: 47).

To the extent that subsistence production was undermined by severing the "vertical," multi-zonal, strategies of pre-Conquest *ayllus*, the *reducciones* served as a built environment favorable to the consolidation and reproduction of the mining-centered commodity economy.

The *reducciones* insisted on a new agro-ecological order corresponding to the labor demands of the silver frontier. At its center was common-field agriculture, a cultivation system that emphasizes agro-pastoral linkages, access to commons, and community regulation of landholding (Thirsk 1964). Where verticality presumed exchanges across ecological zones, such that farming and herding were "geographically nonoverlapping activities," common-field agriculture sundered such exchanges by stressing agro-pastoral integration *within*, rather than between, zones (Godoy 1991: 396-98).

From the standpoint of the colonial state, the advantage of the common-field system was its geographically expansive character. The new agro-ecological order mobilized land as the best way to maximize labor productivity. Thus it was not simply that Spanish colonialism carried new disease vectors that eviscerated indigenous populations. The very agro-ecological regime constructed under Spanish hegemony was premised on the scarcity of labor power. Insofar as it demanded the destruction of pre-Conquest social organization (such as the *ayllus*) and the construction of an urban semi-proletariat (and servile laboring classes on the Spanish estates), this regime sustained and indeed *presumed* the long-run demographic contraction.

The new system minimized the labor power formerly allocated to supervising and guarding herds and fields, and maintained soil fertility by substituting European livestock for vertical guano transfers (Godoy 1991: 408-9; Gade 1992: 467). (This also tended to accelerate soil erosion, as we've seen.) The transition was accelerated by Viceroy Toledo's 1575 "edict mandating a plow and oxen for each Indian agglomeration" (Gade 1992: 469). The 1575 edict codified an epochal shift in Andean political ecology, from a labor-intensive to a land-extensive approach. Wolf's observation on sixteenth century Mexico is easily applied to Peru:

> Where the Indians had farmed land with a dibble, the Spaniards introduced a light plow drawn by oxen. ... With this new instrument, men were probably able to farm land which they had not farmed before: the plow with a metal tip is a much better tool for loosening deep sod and breaking up the tangle of roots and rhizomes than the hoe. ... [*Yet,*] i*n its net effect, the plow also upset the balance of Indian life on the land. The plow is efficient only where land is plentiful but labor is scarce.* Plow agriculture does not produce as much as hoe cultivation on any given unit of land. ... Also, plow agriculture means that oxen must be fed, and some land must be devoted to their care. ... [E]very unit of land withdrawn from Indian agriculture meant a halving of the food supply on that land [assuming that hoe yield ratios were twice that of plow ratios], and thus a halving of the population dependent on that food supply. And when that land was planted to wheat to feed the Spanish conquerors [or workers in the mines] rather than the Indian inhabitants ... the growing imbalance between man and land was intensified (Wolf 1959: 198-99, emphasis added).

The livestock-plow system was complemented, in fact made possible by, a second moment of ecological imperialism. This was marked by the invasion of Europeans' favored crops, wheat above all. Demand for wheat was high from the earliest moments of Spanish colonization, and commercial production dates from the late 1530's (Keith 1976: 66). "In some locales [Indians] were growing it as ... [a] food staple by the late sixteenth century" (Gade 1992: 465). If the common-field system reduced necessary labor by cutting supervision costs, and the livestock-plow system effectively substituted land and animal power for human labor, wheat offered a further labor-saving (but land-consuming) bonus. Relative to indigenous crops, wheat demanded little labor and enabled plow agriculture by tolerating the new animals' grazing patterns (Godoy 1991: 407; Gade 1992: 165-66).

In early modern Europe, wheat's agro-ecological trade-off was its tendency towards low yields and soil exhaustion. Wheat "devours the soil and forces it to rest regularly" (Braudel 1977: 11). Peru's fertile soils, however, counteracted this tendency for a time. Indeed, in coastal zones, multiple cropping with high-yields could be sustained for several years (Descola 1968: 225). Estimates vary on just how fertile this soil was. Primary sources suggest extraordinary harvests. Espinosa says that with guano, wheat yields of 1:1,000 were possible in a district close to Potosí (1628: 518). Surely a literary flourish, although Super reports yields of between 1:50 and 1:100 (1988: 20-23).

Quite possibly, the introduction of wheat and other Eurasian grains enjoyed a period— how long it is difficult to say, but likely not more than 20 years— of substantial freedom from pests and diseases. This "yield honeymoon" (Dark and Gent 2001) would have allowed higher yields and given settlers the impression of endless bounty. Reports of cereal yields ranging from 1:50 to 1:100 are also found in the reports of fifteenth-century visitors to Madeira (Cadamosto 1455). Yield honeymoons were a recurrent source of the "windfall" profits in the rise of capitalism. Even if we take with a grain of salt the exuberant reporting of Espinosa and his contemporaries, it appears that on balance wheat cultivation in Peru supported seed/yield ratios 3-6 times higher than those obtaining in seventeenth-century Europe, liberating still more labor from agriculture (Slicher van Bath 1963: 330; Super 1988: 20-2; Keith 1976: 66). Wheat's ecology could not be ignored completely: the tendency towards soil exhaustion necessitated frequent fallow periods and livestock to restore fertility. Hence the importance of the common-field (Assadourian 1992: 62). Peruvian soil did, however, prove hospitable to the transfer of a European agronomic complex that created a relative surplus population in the face of demographic contraction, and provided a crucial subsidy for early Spanish commercial agriculture.

Nor was this the end of the Spaniards' agro-ecological bonanza. Also among these windfalls was the potato. Not only were its labor requirements minimal. Its yields were vastly greater. While corn (maize) is also a labor-minimizing crop, a hectare planted with potatoes will yield some 5-6 *times* the food volume of a comparably sized corn field (Braudel 1981: 158-63; Browman 1974: 190). Contemporary maize yields in pre-Conquest New Spain and Central America were already two to three times greater than per hectare cereal output in sixteenth-century Europe (Malanima 2006: 106). Even with higher wheat yields on American soil, then, potato cultivation yielded, at a minimum, twice as much as Eurasian grains.

Achieving its "clearest expression" and most durable form in those villages most heavily burdened by mining frontier's labor demands, common-field agriculture responded well to the colonial state's demand for a "reservoir of cheap labor for the mines" (Godoy 1991: 405). The net supply of laborers increased, but only for a time. The *reducciones* and common-field agriculture helped to create a regional commodity-oriented political ecology that sustained demographic decline into the eighteenth century and thus the demise of the very labor surplus it had created.

Providing the administrative and spatial framework for the *mita*, the *reducciones* established the conditions for yet deeper transformations of land and labor in the service of capital. While it is customary within environmental history to explain these transformations in terms of the power of the market,[6] our story of the silver frontier so far suggests a multi-faceted explanation. The geographical expansion of the commodity system was predicated on a wider ensemble of socio-ecological relations. Foremost among these was power of the state to create and sustain the conditions for expanded commodification. This was no mere "Smithian" dynamic (*pace* Brenner 1977). To be sure, colonials established commercial agriculture in response to commercial opportunities, especially those arising from the mining frontier. (How could it be otherwise in a region where something like one-third of the silver produced stayed put?[7]) But this development presupposed the disrupting effects of Europe's social and biological expansion, which transformed indigenous society in ways that encouraged a significant (if still partial) turn towards commodification.

We can identify three main sources of disruption linked to the silver frontier's commercializing impulse: 1) land expropriation; 2) stockraising and the imperial moment of Crosby's "Columbian Exchange" (1972); and 3) the spatio-temporal dynamics of the *mita* itself. The first, as we have seen, was the colonial state's relocation of native communities. This often amounted to outright land theft. Concentrating scattered Indian settlements, the *reducciones* opened up vast new expanses for colonial agriculture and stockraising (Ramirez 1987: 598; Charney 2001: 17-8, 44). And this was only the beginning. In the half-century after 1570, the land appropriation escalated still further. Was it happenstance that the turning point in Peru coincides with a seigneurial offensive in Spain that led to the widespread dispossession of small cultivations and rising concentration of landownership? The mechanisms of dispossession were different, but in Peru and Castile alike the number and size of large estates increased several times over (da Silva 1964). In Peru, this was made possible largely through the state's "direct intervention ... accelerat[ing] the distribution of land to the Spanish settlers" (Assadourian 1992: 60). European conceptions of private property were beginning to supplant indigenous notions of communal property (Ramirez 1996: 73-4; Andrien 2001: 81-2). And since landholdings were useless without labor, the colonial state mobilized an agricultural *mita* five times larger than New Spain's (Assadourian 1992: 61), a differential that reflected the two regions' silver output. By 1630, haciendas "dominated the urban and mining markets" for maize, and presumably for wheat as well (Assadourian 1992: 62; also Stern 1982: 109)

This dual process of land clearance and land appropriation, whose greatest impetus was the mining frontier, was made easier by rapid depopulation owing to Eurasian disease (Smith 1970; Keith 1976: 42-7). But as I've suggested, depopulation cannot be explained solely in terms of the initial epidemiological onslaught. Among the factors driving prolonged demographic decline was the proliferation of Old World animals deliberately introduced to aid the colonial project (Mann 2002). Pigs were a big factor. As Melville puts it, "anyone who has [had] to deal with pigs in their garden will know the remarkably short period of time needed for just one pig to wreak havoc" (1994: 50).

These livestock did more than carry disease. Particularly in the case of sheep and cattle, Eurasian beasts entered into competition with the overall *system* of indigenous cultivation, dramatically undermining these societies' socio-biological reproduction (Crosby 1972: 98-9; Parry 1963: 246). The classic instance of this process is New Spain in the sixteenth and seventeenth centuries, where the livestock economy was also given life by the silver mining frontier (Simpson 1952; Wolf 1959; Melville 1994). There were, to be sure, important points of divergence between colonial New Spain and Peru—foremost among these the Andean traditions of llama- and alpaca-herding, which facilitated indigenous stockraising after Conquest. Nevertheless, in both regions the underlying logic of the agro-pastoral "footprint" was the same. By the late sixteenth century, a rising cattle population inflicted widespread damage on Indian fields, leading peasants to move "their fields outside the range of the roaming beasts. ... Once the peasants abandoned the land, the Spanish moved in permanently and grazed it or cleared it" (Ramirez 1996: 73-4). Once relocated to the *reducciones*, Andean peasants found little respite. These colonial nucleations, alas, were located at some remove from the fields, often several kilometers or more distant. Hence, a century later, the clear trend was for peasants in the *reducciones* to re-establish themselves closer to the fields "to guard the crops from livestock damage" (Gade and Escobar 1982: 441).

Depopulation played its role in the withering of the remarkable hydraulic infrastructure of the Inca Empire, but so did the Eurasian livestock invasion. The Andean chronicler Guaman Puma (Felipe Guaman Poma de Ayala), writing between 1600 and 1615, vividly describes the agro-ecological transition:

> And so throughout the kingdom [before the Conquest] all lands produced food. ... And the Inca kings commanded that no one should damage or remove one stone, and that no livestock should enter the aforementioned canals [irrigation works] ... But

> now this law no longer applies. And so all the fields are destroyed because of a shortage of water. On account of this the Indians lose their lands. ... For nowadays the Spaniards let loose their animals, their mule trains or their cows, their goats and pigs, and they cause great damage. And they take the water and destroy the irrigation canals so much so that no amount of money could repair them. And the little amount of water that remains, that also is taken from the poor Indians. And so the Indians abandon their towns (Poma de Ayala 1980: 885; also Zimmerer 2000: 166).

Naturally, where the colonials were moving aggressively to establish cash crop production, wheat for instance in the Cochabamba valley basin (Larson 1988), the story was different. Cochabamba, subordinated in 1539, was too arid to support the emergence of large-scale agriculture that sustained Potosí. Instead of destroying Incaic hydraulic infrastructure, the Spaniards appropriated it: "in many cases ... [the Spanish] preferred the tactic of usurping the intact Indian waterworks" (Zimmerer 2000: 164).

Potosí's voracious appetite for labor, satisfied in large measure through the *mita*, was a third source of disruption. Knitting together the region's pueblos in a new town-country division of labor, the *mita* created a favorable disease environment whose effects were felt in "murderous epidemic" (Lovell 1992: 436; also Cole 1985: 28). This contradiction was reinforced by others. By extracting hypothetically "surplus" labor from the villages, the *mita* undermined socio-ecological reproduction over the short- and long-run. In the first instance, the *mita* often withdrew labor at "crucial moments in the agricultural cycle," further destabilizing labor-intensive cultivation (Stern 1982: 89). This would have been bad enough, all things being equal. But of course all things were not equal. The disruption of the *mita* intruded at the very moment when the imposition of the common-field system necessitated a quantum leap in the village-level coordination of stockraising and agriculture. Formerly separated spatially, under pre-Conquest principles of verticality, the "radical transformation of land tenure" effected by Toledo's grand strategy after 1571 placed this agro-pastoral regime under one roof (Zimmerer 1997: 50). Zimmerer, looking at Conquest-era Pautarcambo, a key coca-producing zone intimately linked with Potosí even though 500 miles distant, cuts to the heart of the contradiction. "Any shortcutting" of the coordination between stockraising and cultivation—that is, the very coordination that the *mita* threatened to undermine—"was likely to result in crop damage. The map of new partitioned lands ... inferred deteriorating soil fertility and worsened erosion in areas nearest villages due to the contracted periods of fallow and the loss of community control over cropping and livestock" (1997: 51).

When *mitayos* returned, many were too sick to return to work the land, others found their fields "deteriorating or unworked" (Stern 1982: 87). But many did not return. There was a long-term hemorrhaging of labor, as *mitayos* left permanently (becoming semi-proletarian *forasteros*), many of them taking up residence in the mining camps and haciendas (Andrien 2001: 86; Godoy 1991: 406). By the early seventeenth century there were some 76,000 Indians, an early mining semi-proletariat, in Potosí, quite distinct from those workers bound by the *mita* (Cole 1985: 66). Between 1581 and 1609, villages within the Potosí *mita* lost one-third to one-half their population, with even sharper declines in some locales (Bakewell 1987: 231; Barber 1932: 105; Cobb 1947: 79-81; Cole 1985: 27-8). This "*collective* deterioration" of village life (Stern 1982: 89)— by means of the cash nexus and the colonial state— would over time undermine the conditions of profitability for the region's mining complex, already in the grips of a profit-squeeze from above owing to the overproduction of silver on the global market (Flynn and Giraldez 2002).

And yet the demographic contraction did not stabilize during Potosí's decline in the later seventeenth century, at least not everywhere and in many regions in which the *mita*'s geographical reach was *initially* weakest. By 1672, the viceroy Conde de Lemos inveighed against local officials who compelled villagers to travel to Potosí for the mine work *even though* the villages could pay cash (Premo 2000: 83); this was a sure sign of rising labor costs even in the era of the Cerro Rico's secular decline. The labor draft was undermining the socio-biological basis of the whole complex. Understandably, the viceroy was concerned with tax revenues, as were contemporary Absolutist states *within* Europe (de Vries 1976: 30-83). Given the progressive commutation of labor dues into cash payment, depopulation meant declining cash revenues for the Crown. Conde de Lemos argued in 1673 that "if [the male villagers] are continually forced to work [in the mines], they abandon their lands, houses and families in order to liberate themselves, to the grief of their children and of wives" (quoted in Premo 2000: 83). A year earlier he made much the same argument, specifying the growing problem of malnutrition— one of the hallmarks of underdevelopment from its earliest moments (Galeano 1973; Castro 1966)— contending that the *mita*'s labor draft had so disrupted village agriculture that "the women and children are left without anything to eat" (quoted in Premo 2000: 83).

Village depopulation, the formation of a mining semi-proletariat, and declining ore quality in Potosí combined to favor the gradual substitution of cash payments for labor service. However uneven in practice, generalization of the cash nexus would significantly alter the relation between indigenous society and the land. It was becoming "clear to all concerned that the *mita* was little more than a heavy tax burden," even as early as the seventeenth century (Andrien 2001: 76). In 1606, silver payments satisfied some 20 percent of the *mita*'s obligations. Two decades later, the figure would climb to somewhere between one-third to one-half (Andrien 2001: 62). "Whatever the actual fraction of the *mita* that was satisfied in money, the sums involved were enormous" (Cole 1985: 37). The indigenous political class (*kurakas*) responded by turning to commodity production, largely as a bad solution to a worse situation. Eurasian crops such as wheat and barley were especially favored (Godoy 1991: 306; Spalding 1975: 111). While some *kurakas* grew rich, more generally commodity production was associated with rising indebtedness and land alienation (Ramirez 1996: 119). The political ecology of colonial taxation therefore favored a radical simplification of pre-Conquest agriculture, favoring Eurasian cereals over those "diverse [American] crops [such as the potato] that were hardy and rarely failed completely" (Zimmerer 1997: 55). This development was fraught with unhappy implications for indigenous socio-biological reproduction:

> As tribute and other community obligations increased, these lands were often sold or rented to discharge debts. Shortages of labor and land at times [of] increased extra-communal demands on Indian communities led to food shortages and even famines. These situations resulted not only in acute starvation in some cases but also in malnutrition, which increased the susceptibility of Indians to illness and disease and probably reduced the effective birthrate through maternal malnutrition during pregnancy and lactation (Newson 1985: 56).

Increasingly frequent famines, and the generalization of malnutrition that ensued (Cook 1981; Klaren 2000: 49), expressed the dietary moment of what we might call *extroverted primitive accumulation* in the Americas. An *ecological surplus* was extracted from the bodies and fields of the indigenous peasantry in a way that paralleled the extraction of surplus labor, in both instances for the benefit of accumulation centers abroad rather than the creation of a home market. This was the "disarticulated"— *and therefore intrinsically globalizing*— nature of the New World's metabolic rift in the transition to capitalism.

Potosí's decline in world-historical perspective: ecology, capital, and the spaces of accumulation

Potosí remained an important silver producer until the nineteenth century. But the Cerro Rico's moment in the sun was over by 1640, perhaps earlier. Bakewell identifies 1615 as the definitive moment of decline in silver output (1975), although its relative decline would not become fully apparent until the end of the century, with the rise of New Spain as the world-system's leading producer. Potosí's output was essentially the same in 1715 as it was in 1640. And although it would make an "impressive recovery" in the eighteenth century, surpassing its production peak of the late sixteenth century, this would give way to sustained contraction almost immediately. This depression— was it coincidence that that these were also the years of the Tupac Amaru revolt?— would endure "at least until 1810" (Garner 1988: 903). By 1825, there were just 8,000 people living in Potosí (Hanke 1936).

Peru's loss was Mexico's gain. Silver mintage quadrupled in New Spain between 1706 and 1798 (Brading and Cross 1972: 576). Given the extent of smuggling and the informal economy, the increase was likely even more spectacular. New Spain accounted for nearly two-thirds of world silver output (64.4 percent) by the close of the eighteenth century, at the very moment of Peru's mining depression (c. 1780-1810) (Dobado and Marrero 2006: 9). It was "an almost exact reversal of the position of a century earlier." Where Potosí had once dwarfed Zacatecas' output in the seventeenth century by a factor of seven to one, now Guanajuato alone— New Spain's leading silver producer and in contrast to seventeenth-century Potosí merely a *primus inter pares*— outstripped Potosí's output in the later eighteenth century (Spate 2004: 195).

Why the shift from Peru to New Spain? Among the unusual features of the Peruvian silver revolution is that Potosí's expansion *begins* at the moment of overproduction. "Thus *in the long term*, the value of silver increased from the thirteenth to the sixteenth century, until roughly 1550" (Braudel 1981: 459). What this means is fairly clear. The imperial and capitalist agencies behind the silver commodity frontier were able to drive down costs to such an extent that they were able to outrun downward price movement (aided and abetted, of course, by geological good fortune.) This was a successful strategy through the 1620's, possibly a bit longer.

There were three decisive moments to this historical-geographical movement: 1) the success of the *mita*; 2) the relation of East Asia to the emergent capitalist world-ecology; and 3) the production of nature. Each moment was contradictory, self-propelling and therefore self-limiting. The very speed with which the Potosí veins were exploited at once led to rising costs apace with (and partially independent of) declining ore yields. This underproduction tendency met up with overproduction, as global silver prices fell about one percent per annum between 1540 and 1640 (Flynn and Giraldez 2002: 404-405).

Potosí was able to skate ahead of both curves (underproduction and overproduction), at least until the 1620's, for reasons that go far beyond the introduction of the mercury amalgamation process. The technical moment is indeed crucial, although perhaps not nearly so much as Bakewell (1984, 1987) and Braudel would have it (1981: 460). The *mita* and the socio-spatial strategy of the *reducciones* were equally decisive moments. This imperial refashioning of Peru was of course the American face of primitive accumulation (*one* of its faces), working its gruesome logic at a scale and speed unfathomable in the European heartland. The historical-geographical specificity of primitive accumulation in the Americas, what I have called *extroverted primitive accumulation*, is dismissed at one's peril.

Primitive accumulation in Peru was particularly successful in one crucial respect. In contrast to New Spain, the *mita*'s spatial program enabled the colonial state to marshal a huge supply of low-cost *and tractable* labor in the midst of sustained demographic contraction. It is no accident that New Spain's ascent to the commanding heights of silver production awaited the revival of its demographic base. Certainly geology had something to do with the differences as well. The Cerro Rico *was* the silver commodity frontier. There were other mines, but none came close to Potosí during its zenith. The relatively unicentric character of Peru's mining frontier facilitated imperial control in a way the polycentric silver frontiers of New Spain did not.

If the imperial refashioning of the Andes was crucial, so were the competitive and conflict-ridden relations of early modern geopolitics and the world market. This is a second crucial aspect of Potosí's rise and demise. By the mid-sixteenth century, Western Europe's silver exports to the Baltic and to South and East Asia were ramping up and possibly as much as half American silver exports would end up in Asia (Frank 1998: 131-64). Flynn and Giraldez put the figure closer to three-fourths (1999: 23), although this may be too high if we believe Assadourian and his colleagues, who maintain that one-third of Andean silver production remained in the Americas (1980: 24-5). Regardless of the precise figures, it is clear that relative underproduction of silver in Asia braked the tendency towards overproduction in the Americas. Silver exports to zones outside Europe's Atlantic-centered division of labor represented an important means of attenuating the profit squeeze on American mining. Potosí, then, was able to run ahead of supply *and* demand price curves for reasons turning on the fundamentally globalizing character of early modern capitalism.

Our third moment is the production of nature, and this is something beyond the addition of "environmental" factors. The production of nature is shorthand for one of the most powerful insights of the world-historical perspective. This is the contention that capitalism must be analyzed within the totality of its conditions of production and not merely commodity production and exchange. Historical capitalism has sustained itself on the basis of exploiting, and thereby undermining, a vast web of socio-ecological relations. This process of exploitation is not always— indeed not usually— one of direct commodification, as we see in colonial Peru. The commodity frontier strategy effected, in the same breath, the destruction *and* creation of premodern socio-ecological arrangements: "The colonial expansion of capitalism not only absorbed pre-capitalist economic systems; it created them" (Fox-Genovese and Genovese 1983: 59; Moore 2007, 2010a, 2010b, 2010c, 2011).

The key issue is one of the exhaustion of a given complex of socio-ecological relations, necessary to maintain regional competitiveness. This progressive exhaustion, manifesting in rising costs of production for Peru's silver complex, is at the heart of the matter. Deforestation, food insecurity, degraded indigenous irrigation systems, the disruption of planting schedules, mercury poisoning, demographic contradiction, soil erosion, these are all important clues to the inner dynamics of capitalism, but tell us little about world-ecological change. What merits closer attention is a world-historical inflection on the Polanyian argument (1957). As we see in colonial Peru, the rapid "fictitious" commodification of labor and land undermined the socio-ecological bases for the regional accumulation regime, setting the stage not just for the eventual resurgence of the "self-protecting society" but also for a new round of global expansion. Hence the recurrent waves of global conquest, from Central Europe to Peru to New Spain.

This is the core argument of the theory of the commodity frontier. It is a response to Genovese's cogent observation that the "rise of capitalism requires a theory that includes the inability of the soil [along with the rest of nature!] to recover sufficient productivity to maintain a competitive position" (1967: 88). It was precisely the inability of regional socio-ecological formations to *regain* the competitive edge (once lost) that underpinned early capitalism's profound geographical restlessness. It is therefore the question of regional centrality in world accumulation that is of paramount importance. And it was this position of centrality that Central Europe relinquished to Potosí in the mid-sixteenth century, and that Potosí would relinquish, in turn, to New Spain at the dawn of the eighteenth century.

Endnotes

[1] The author wishes to thank Diana C. Gildea, MacKenzie Moore, Dale Tomich, and Richard A. Walker for conversations on the issues explored in this paper.

[2] Epinosa visited Potosí c. 1616, at the very height of the boom.

[3] Far from an isolated event, deforestation around Potosí signified a structural tendency of the new colonial order throughout the Viceroyalty of Peru: "[T]he presence of innumerable small-scale mines and some much larger operations suggests the area [Northern Potosí] may have begun to become barren of aborescent vegetation during this [the colonial] period" (Godoy 1984: 368).

[4] Metallic mercury can be flushed from the body with much greater ease than biomethylated mercury, such as that absorbed by eating polluted fish.

[5] Similarly large volumes of mercury appear were dumped Mexico during the colonial period. See the report issued by Acosta y Asociados (2001).

[6] See Cronon (1991), Richards (2003).

[7] See Assadourian et al. (1980: 24-25).

References

Acosta, José de (1590 [1604]) *The naturall and morall historie of the East and West Indies*, London, Edward Blount and William Aspley

Acosta y Asociados (2001) *Inventory of Sites in Mexico with Elevated Concentrations of Mercury: Preliminary Draft Report*, Agua Prieta, Sonora, Mexico, Acosta y Asociados

Andrien, K.J. (2001) *Andean Worlds*, Albuquerque, University of New Mexico Press

Anonymous (1603 [1885]) *Descripcion de la Villa y Minas de Potosí— Ano de 1603*, in Ministerio de Fomento (ed.), *Relaciones Geograficas de Indias*, Vol. II, Madrid, Ministerio de Fomento, 113-36

Arrighi, Giovanni (1994) *The Long Twentieth Century*, London, Verso

Assadourian, C.S. (1992) 'The colonial economy', *Journal of Latin American Studies*, 24, (Quincentenary Supplement), 52-68

Assadourian, C.S., Herclio Bonilla, Antonio Mitre, and Tristan Platt (1980) *Mineria y Espacio Economico en los Andes, siglos XVI-XX*, Lima, Instituto de Estudios Peruanos

Bakewell, P.J. (1975) 'Registered silver production in the Potosí district, 1550-1735', *Jahrbuch fur Geschichte von Staat, Wirtschaft und Gesselschaft Lateinamerikas*, 12, 67-103

Bakewell, P.J. (1984) *Miners of the Red Mountain*, Albuquerque, University of New Mexico Press.

Bakewell, P.J. (1987) 'Mining', in L. Bethell (ed.), *Colonial Spanish America*, Cambridge, Cambridge University Press, 203-49

Bakewell, P.J. (1988) *Silver and Entrepreneurship in 17th Century Potosí*, Dallas, Southern Methodist University Press

Barba, A.A. (1640 [1674 edition]) *The Art of Metals*, London, S. Mearne

Barber, Ruth Kearns (1932) *Indian Labor in the Spanish Colonies*, Albuquerque, University of New Mexico Press

Barrett, Ward (1990) 'World bullion flows, 1450-1800', in J.D. Tracy (ed.), *The Rise of Merchant Empires*, Cambridge, Cambridge University Press, 224-54

Born, Baron Inigo (1791) *New Process of Amalgamation of Gold and Silver Ores, and other Metallic Mixtures*, London, T. Caldwell

Brading, D.A., and H.E. Cross (1972) 'Colonial silver mining: Mexico and Peru', *Hispanic American Historical Review*, 52 (4), 545-79

Braudel, Fernand (1953) 'Qu'est-ce que le XVIe Siècle?' *Annales E.S.C.*, 8 (1), 69–73

Braudel, Fernand (1972) *The Mediterranean and the Mediterranean World in the Age of Philip II*, Vol. I., New York, Harper & Row

Braudel, Fernand (1977) *Afterthoughts on Material Civilization and Capitalism*, Baltimore, Johns Hopkins University Press

Braudel, Fernand (1981) *The Structures of Everyday Life*, New York, Harper & Row

Braudel, Fernand (1984) *The Perspective of the World*, New York, Harper and Row

Brenner, Robert (1977) 'The origins of capitalist development: a critique of neo-Smithian Marxism', *New Left Review*, 104, 25-92

Browman, D.L. (1974) 'Pastoral nomadism in the Andes', *Current Anthropology*, 15 (2), 188-96

Brown, K.W. (2000) 'Workers' health and colonial mercury mining at Huancavelica, Peru', *The Americas*, 57 (4), 467-96

Cadamosto [Alvise da Ca' da Mosto] (1455 [1967]) *The Voyages of Cadamosto and Other Documents on Western Africa in the Second Half of the Fifteenth Century*, Nandeln, Liechtenstein, Kraus Reprint

Capoche, Luis (1585 [1959]) *Relaciones General de la Villa Imperial de Potosí*, Lewis Hanke (ed.), Madrid, Atlas

Castro, Josué de (1966) *Death in the Northeast*, New York, Random House

Charney, Paul (2001) *Indian Society in the Valley of Lima, Peru, 1532-1824,* Lanham, University Press of America

Cieza de León, Pedro de (1553 [1998]) *The Discovery and Conquest of Peru,* Durham, Duke University Press

Clark, Brett and J.B. Foster (2001) 'William Stanley Jevons and *The Coal Question*', *Organization & Environment,* 14 (1), 93-8

Cobb, Gwendolin (1947) *Potosí and Huancavelica*, Ph.D. dissertation, Department of History, University of California, Berkeley

Cobb, Gwendolin (1949) 'Supply and transportation for the Potosí mines, 1545-1640', *Hispanic American Historical Review*, 29, 25-45

Cobo, B. (1653 [1964]) *Obras del P. Bernabe Cobo de la Compania de Jesus*, Vol. I: *Historia del Nuevo Mundo,* P. Francisco Mateos (ed.), Madrid, Ediciones Atlas

Cole, J.A. (1985) *The Potosí Mita, 1573-1700,* Stanford, Stanford University Press

Cook, N.D. (1981) *Demographic Collapse,* Cambridge, Cambridge University Press

Cooke, C.A., P.H. Balcomb, H. Biesterc, and A.P. Wolfe (2009) 'Over three millennia of mercury pollution in the Peruvian Andes', *Proceedings of the National Academy of Sciences,* 106 (22), 8830-34

Craig, A.K. (1993) 'The ingenious *Ingenios*: Spanish colonial water mills at Potosí', in Kent Mathewson (ed.), *Culture, Form, and Place*, Baton Rouge, Louisiana State University Press

Cronon, William (1991) *Nature's Metropolis,* New York, W.W. Norton

Crosby, A.W., Jr. (1972) *The Columbian Exchange*, Westport, Greenwood Press

Crosby, A.W., Jr. (1986) *Ecological Imperialism*, Cambridge, Cambridge University Press

Dark, Petra, and Henry Gent (2001) 'Pests and diseases of prehistoric crops', *Oxford Journal of Archaeology,* 20 (1), 59-78 de France, S.D. (2003) 'Diet and provisioning in the high Andes', *International Journal of Historical Archaeology*, 7 (3), 99-125

Descola, Jean (1968) *Daily Life in Colonial Peru 1710-1820*, London, George Allen and Unwin, Ltd.

Dobado, R. and G.A. Marrero (2006) 'Mining-led growth in Bourbon Mexico, the role of the state, and the economic cost of independence', *Working Paper* 06/07-1, David Rockefeller Center for Latin American Studies, Harvard University

Dore, Elizabeth (2000) 'Environment and society: long-term trends in Latin American mining', *Environment and Society*, 6, 1-29

DuPlessis, R.S. (1997) *Transitions to Capitalism in Early Modern Europe*, Cambridge, Cambridge University Press

Ellenberg, H. (1979) 'Man's influence on tropical mountain ecosystems in South America', *Journal of Ecology*, 67 (2), 401-16

Elliot, J.H. (1963) *Imperial Spain 1469-1716*, New York, Mentor

Espinosa, A.V. (1628 [1942 edition]) *Compendium and Description of the West Indies: Smithsonian Miscellaneous Collections*, Vol. 102, Washington, D.C., The Smithsonian Institution

Favre, Henri (1975) 'Le peuplement et la colonisation agricole de la steppe dans le Pérou central', *Annales de Geographie*, 464, 415-41

Ferry, S. (2000) 'Potosí's mountain of misery and riches', *The Americas*, 54, 30-9

Flynn, D.O. and A. Giraldez (1999) 'Spanish profitability in the Pacific', in D.O. Flynn, L. Frost, and A.J.H. Latham (eds.), *Pacific Centuries*, London, Routledge

Flynn, D.O. and Arturo Giraldez (2002) 'Cycles of silver', *Journal of World History*, 13, (2), 391-427

Foster, J. (2000) *Marx's Ecology*, New York, Monthly Review Press

Fox, K.V. (1962) 'Pedro Muniz, Dean of Lima, and the Indian labor question', *Hispanic American Historical Review*, 42 (1), 63-88

Fox-Genovese, E. and E.D. Genovese (1983) *The Fruits of Merchant Capital,* Oxford, Oxford University Press

Frank, A.G. (1998) *ReOrient,* Berkeley, University of California Press

Frezier, Monsieur (1717) *A Voyage to the South-Sea And Along the Coasts of Peru, in the Years 1712, 1713, and 1714,* London. Jonah Bowyer

Gade, D.W. (1992) 'Landscape, system, and identity in the post-conquest Andes', *Annals of the Association of American Geographers*, 82 (3), 460-77

Gade, D.W., and Mario Escobar (1982) 'Village settlement and the colonial legacy in southern Peru', *Geographical Review,* 72 (4), 430-49

Galeano, Eduardo (1973) *The Open Veins of Latin America,* New York, Monthly Review Press

Garner, R.L. (1988) 'Long-term silver mining trends in Spanish America', *American Historical Review,* 93 (4), 898-935

Genovese, E.D. (1967) *The Political Economy of Slavery,* New York, Vintage

Gioda, A., C. Serrano, and M. Frey (1998) 'L'eau et l'argent à Potosí', *La Houille Blanche*, 7, 65-75

Godoy, R.A. (1984) 'Ecological degradation and agricultural intensification in the Andean highlands', *Human Ecology,* 12 (4), 359-74

Godoy, Ricardo A. (1991) 'The evolution of common-field agriculture in the Andes', C*omparative Studies in Society and History,* 33, 395-414

Goldwater, L.J. (1972) *Mercury,* Baltimore, York Press

Gomez de Cervantes, Gonzalo (1599 [1994]) *La Vida Economic y Social de Nueva Espana al Finalizar el Siglo XVI* (Mexico City, Antigua Libreria Robredo, 1969), in R.S. Flores, 'Technology of mining in colonial Mexico', in A.K. Craig and R.C. West (eds.), *In Quest of Mineral Wealth.* Baton Rouge, Louisiana State University Press, 150-155

Hamilton, E.J. (1934) *American Treasure and the Price Revolution in Spain, 1501–1650,* Cambridge, Harvard University Press

Hanke, Lewis (1936) 'Statement concerning the contents of the *Historia de la Villa Imperial de Potosí*', *Journal de la Société des Américanistes*, 28 (2), 401-4

Hanke, Lewis (1956) *The Imperial City of Potosí*, The Hague, Martinus Nijhoff

Hribal, J.C. (2003) 'Animals are part of the working class', *Labor History*, 44 (4), 435-53

Jevons, W.S. (1906) *The Coal Question*, Third edition, rev., London, Macmillan

Kamen, Henry (1971) *The Iron Century: Social Change in Europe, 1550-1660*, London, Weidenfield and Nicolson

Kamen, Henry (1994) 'The Habsburg lands: Iberia', in T.A. Brady, Jr., H.A. Oberman, and J.D. Tracy (eds.), *Handbook of European History, 1400-1600 Vol. I*, Grand Rapids, Wm. B. Eerdmans Publishing Co., 467-98

Keith, R.G. (1976) *Conquest and Agrarian Change*, Cambridge, Harvard University Press

Klaren, P.F. (2000) *Peru, Society and Nationhood in the Andes*, New York, Oxford University Press

Kriedte, Peter (1983) *Peasants, Landlords, and Merchant Capitalists*, Cambridge, Cambridge University Press

Larson, Brooke (1988) *Colonialism and Agrarian Transformation in Bolivia*, Princeton, Princeton University Press

Lovell, W.G (1992) '"Heavy Shadows and Black Night": disease and depopulation in colonial Spanish America', *Annals of the Association of American Geographers*, 82 (3), 426-43

Lynch, Martin (2002) *Mining in World History*, London, Reaktion Books

de Maddalena, Aldo (1974) 'Rural Europe 1500-1700', in C.M. Cipolla (ed.), *The Fontana Economic History of Europe, II*, London, Fontana, 273-353

Malanima, Paulo (2006) 'Energy crisis and growth 1650-1850', *Journal of Global History*, 1, 101-21

Mann, Charles C. (2002) '1491', *Atlantic Monthly*, 289 (3), 41-53

Marx, Karl (1967) *Capital*, 3 vols., Frederick Engels (ed.), New York, International Publishers

Marx, Karl (1973) *The Grundrisse*, New York, Vintage

Marx, Karl (1977) *Capital*, Vol. I, New York, Vintage

McNeill, J.R. (1992) *The Mountains of the Mediterranean World*, Cambridge, Cambridge University Press

Melville, E.G.K. (1994) *A Plague of Sheep*, Cambridge, Cambridge University Press

Moore, J.W. 2000 'Environmental crises and the metabolic rift in world-historical perspective', *Organization & Environment*, 13 (2), 123-58

Moore, J.W. (2003a) '*The Modern World-System* as environmental history? ecology and the rise of capitalism', *Theory & Society*, 32 (3), 307-77

Moore, J.W. (2003b) 'Capitalism as world-ecology: Braudel and Marx on environmental history', *Organization & Environment*, 16 (4), 431-58

Moore, J.W. (2007) *Ecology and the Rise of Capitalism*, Ph.D. dissertation, Department of Geography, University of California, Berkeley

Moore, J.W. (2010a) 'Amsterdam is standing on Norway', part I: the alchemy of capital, empire, and nature in the diaspora of silver, 1545-1648', *Journal of Agrarian Change*, 10 (1), 35-71

Moore, J.W. (2010b) 'Amsterdam is standing on Norway', part II: the global north Atlantic in the ecological revolution of the seventeenth century', *Journal of Agrarian Change*, 10 (2), 188-227

Moore, J.W. (2010c) 'The end of the road? agricultural revolutions in the capitalist world-ecology, 1450-2010', *Journal of Agrarian Change*, 10 (3), 389-413

Moore, J.W. (2011, in press) 'Transcending the metabolic rift: towards a theory of crisis in the capitalist world-ecology', *Journal of Peasant Studies*, (38) 1

Mumford, J.R. (2004) *Vertical Empire*, Ph.D. dissertation, Department of History, Yale University

Murra, J.V. (1984) 'Andean societies', *Annual Review of Anthropology*, 13, 119-41

Newson, L.A. (1985) 'Indian population patterns in colonial Spanish America', *Latin American Research Review*, 20 (3), 41-74

Nriagu, J.O. (1994) 'Mercury pollution from the past mining of gold and silver in the Americas', *Science of the Total Environment*, 149 (3), 167-81

Parker, G. (1974) 'The emergence of modern finance in Europe, 1500-1730', in C.M. Cipolla (ed.), *The Fontana Economic History of Europe II*, 527-94

Parker, G. (1979) *Europe in Crisis 1598-1648*, Ithaca, Cornell University Press

Parry, J.H. (1963) *The Age of Reconnaissance*, New York, Mentor

Parsons, J.J. (1962) 'The cork oak forests and the evolution of the cork industry in southern Spain and Portugal', *Economic Geography*, 38, 195-214

Polanyi, K. (1957) *The Great Transformation*, Boston, Beacon Press

Poma de Ayala, Felipe Guaman [Waman Puma] (1980[c. 1615]) *El Primer Nueva Coronica y Buen Gobierno*. J.L. Urioste, trans., J.V. Murra and Rolena Adorno (eds.), Mexico City, Siglo Veintiuno

Portes, Alejandro (1977) 'Urban Latin America', in J. Abu-Lughod and R. Hay, Jr. (eds.), *Urbanization in the Third World*, Chicago, Maaroufa, 59-70

Premo, Bianca (2000) 'From the pockets of women', *The Americas*, 57 (1), 63-93

Ramirez, S.E. (1987) 'The "Dueno de Indios"', *Hispanic American Historical Review*, 67 (4), 575–610

Ramirez, S.E. (1996) *The World Turned Upside Down*, Stanford, Stanford University Press

Richards, J.F. (2003) *The Unending Frontier*, Berkeley, University of California Press

Rowe, J.H. (1957) 'The Incas under Spanish colonial institutions', *Hispanic American Historical Review*, 37 (2), 155-99

Rudolph, W.E. (1936) 'The lakes of Potosí', *Geographical Review*, 26 (4), 529-54

Sale, Kirkpatrick (1990) *The Conquest of Paradise*, New York, Plume

Sauer, C. (1981) *Selected Essays, 1963-1975*, Berkeley, Turtle Island Foundation

Semo, Enrique (1993) *The History of Capitalism in Mexico*, Lidia Lozano, trans., Austin, University of Texas Press

da Silva, J.-G. (1964) 'Degradazione economica e ristagno secolare: linee di sviluppo del economia Spagnola dopo il secolo XVI', *Studi Storici*, 5 (2), 241-61

Simpson, L.B. (1952) *Exploitation of Land in Central Mexico in the Sixteenth Century*, Berkeley, University of California Press

Slicher van Bath, B.H. (1963) *The Agrarian History of Western Europe, 500-1850 A.D.*, New York, St. Martin's Press

Smith, C.T. (1970) 'Depopulation of the central Andes in the 16th century', *Current Anthropology*, 11, 453-63

Spalding, Karen (1975) 'Hacienda-village relations in Andean society to 1830', *Latin American Perspectives*, 2 (1), 107-21

Spate, Oskar Hermann Kristian (2004) *The Spanish Lake*, Canberra, Australian National University Press

Stephens, Tim (2001) 'Mercury: a toxic legacy', *UC Santa Cruz Review*, 38 (3), 18-21

Stern, S.J. (1982) *Peru's Indian Peoples and the Challenge of Spanish Conquest*, Madison, University of Wisconsin Press

Sundberg, U. (1991) 'An energy analysis of the production at the great copper mountain of Falun during the mid-seventeenth century', *International Journal of Forest Engineering*, 1 (3), 4–16

Super, J.C. (1988) *Food, Conquest, and Colonization in Sixteenth-Century Spanish America*, Albuquerque, University of New Mexico Press

Tandeter, Enrique (1981) 'Forced and free labor in late colonial Potosí', *Past and Present*, 93, 98-136

Teich, Miklaus (1975) 'Born's amalgamation process and the international metallurgic gathering at Skleno in 1786', *Annals of Science*, 32 (3), 5-40

Thirsk, Joan (1964) 'The common fields', *Past & Present*, 29, 3-25

Ulloa, Antonio de (1772) *Noticias Americanas, sorbe la America, y la Septenrioal Oriental, 4to Madrid, 1772: or Accounts of the Southern and North-East America; chiefly on the Amalgamation of Silver Ores, and the Consumption of Quicksilver*, excerpted in Baron Inigo Born (1791) *New Process of Amalgamation of Gold and Silver Ores, and other Metallic Mixtures*, London, T. Caldwell, 63-66

Vega, Garcilaso de la (1608 [1688 edition]) *The Royal Commentaries of Peru, in Two Parts*, London, Miles Flesher

de Vries, Jan (1976) *The Economy of Europe in an Age of Crisis*, Cambridge, Cambridge University Press

Wallerstein, Immanuel (1974) *The Modern World-System I*, New York, Academic Press

Webb, W.P. (1964) *The Great Frontier*, Austin, University of Texas Press

Weisser, M.R. (1982) 'The agrarian depression in 17th-century Spain', *Journal of Economic History*, 42 (1), 149-54

Westermann, E. (1996) 'Central European forestry and mining industries in the early modern period', in S. Cavaiocchi (ed.), *L'Uomo e la foresta*, Firenze, Le Monnier, 927-53

Whitaker, A.P. (1941) *The Huancavelica Mercury Mine*, Cambridge, Harvard University Press

Williams, Eric (1944) *Capitalism and Slavery*, London, Andre Deutsch

Wilson, W.E. and Alfredo Petrov (1999) 'Famous mineral localities: Cerro Rico de Potosí Bolivia', *Mineralogical Record*, 30, 9-36

Wise, J.M. and J. Féraud (2005) 'Historic maps used in new geological and engineering evaluation of the Santa Barbara Mine, Huancavelica mercury district, Peru', *De Re Metallica*, 4, 19-28

Wolf, E.R. (1959) *Sons of the Shaking Earth*, Chicago, University of Chicago Press

Wolf, E.R. (1982) *Europe and the People without History*, Berkeley, University of California Press

Zárate, Agustin de (1555 [1581]) *The Discovery and Conquest of the Provinces of Peru, and the Navigation in the South Sea, Along that Coast and also of the Riche Mines of Potosí*, London, Richard Jones

Zimmerer, K.S. (1997) *Changing Fortunes*, Berkeley, University of California Press

Zimmerer, K.S. (2000) 'Rescaling irrigation in Latin America', *Ecumene*, 7 (2), 150-17

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