Taming Trees: Capital, Science, and Nature in Pacific Slope Tree Improvement

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This article traces the emergence of industrial tree improvement along the Pacific Slope of western Oregon and Washington. Anxieties about timber famine in the United States prompted research on forest genetics and Douglas-fir provenance as far back as 1913, while diminishing supplies of old-growth timber resources in this region led to tree improvement—systematic tree breeding to enhance commercially attractive characteristics—on an industrial scale beginning in the 1950s and 1960s. Throughout, tree improvement has been characterized by a preponderance of co-operation among private, otherwise competitive capitalist firms, with considerable support from state agencies and from science in both research and applied settings. Pacific Slope tree improvement is explored as a case study of the social production of nature by capital and science, particularly the ways in which, in response to natural-resource constraints, the reproductive biology of forest trees has been increasingly targeted, appropriated, and subsumed as a source of industrial productivity. The general absence of exclusively private, proprietary approaches to tree improvement is discussed as a reflection of a set of particular biophysical challenges, including the "problem" of biological time. Thus, while biophysical nature is increasingly socially produced through tree improvement, the social organization of tree improvement bears the inscription of biophysical nature. The article closes with an examination of one of the main avenues by which biotechnology—including genetic engineering—is being incorporated into tree improvement. The new technological possibilities and opportunities for establishing exclusive property rights over plant varieties that biotechnology entails may lead to a more complete model of commodification in tree improvement. Some evidence of such change is already apparent. Though forestry biotechnology is subject to regulatory and wider social sanction, its advent reinforces a main theme in the article: that social and environmental change are interlocking, dialectical processes. *Key Words: Douglas fir region, industrial tree improvement, social production of nature.*

> The long production time (which comprises a relatively small period of working time) and the great length of the periods of turnover entailed make forestry an industry of little attraction to private and therefore capitalist enterprise. (Marx 1967, 248)

> Today's forest practice is based almost entirely on wild forest trees. Unlike crop plants, trees have not undergone centuries of selection and breeding to make them more useful to man [sic]. There is strong evidence that through application of genetic principles we can produce stock that grow twice as fast as the parent stock, that resistance to most major destructive pests can be bred into trees, that specified wood properties can be produced at will. . . . It should be feasible to develop straighter form, fewer limbs and resistance to climatic extremes. (Forestry Research Task Force, U.S. Department of Agriculture, and the Association of State Universities and Land Grant colleges 1967, 34)

In 1913, U.S. Forest Service scientist Thornton Munger began experimental work on the genetics of Douglas fir (*Pseudotsuga menziesii*) in western Oregon and Washington. Using thirteen test plots scattered between the crest of the Cascade Mountains and the Pacific Coast, Munger helped to pioneer American research on seed source, or provenance (Munger and Morris 1936; Bordelon 1988) in seeking to understand how geographic variation in Douglas-fir populations corresponded to different environmental conditions.

In many ways, Munger's experiments reflected important, incipient changes in the geography of the late nineteenth- and early twentieth-century American forest sector. Following rapid expansion and subsequent decline in northeastern, Great Lakes, and southeastern lumbering, U.S. forest capital was turning its eyes increasingly to a region Earl Pomeroy (1991) dubbed "the Pacific Slope,"[1] home to the last great stands of old-growth timber (public and private) in the continental United States (Greeley 1925; Williams 1989). Munger's work built on this regional shift: for example, it followed Frederick Weyerhaeuser's massive purchase of Douglas-fir timberlands from James J. Hill of the Burlington Northern Railroad by slightly more than a decade.[2] Moreover, because Munger was a federal scientist, his 1908 appointment to the region reflected a growing profile for the federal government in the political economy of American forestry (Robbins

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1982), coincident with the rise of scientific forest management (Demeritt 2001b) and with the westward march of lumbering.

And it was Munger who first introduced to the Pacific Slope region (see Figure 1) the emerging science of forest genetics.[3] American foresters showed increasing interest in forest genetics during the early twentieth century, propelled by concerns about the exhaustion of the nation's timber supplies but also inspired by the rediscovery of Gregor Mendel's work in plant breeding and its applications to American agriculture by the likes of Liberty Hyde Bailey and Rowland Harry Bifkin (Perkins 1997). Provenance testing of the sort conducted by Munger originated in European experimental forestry programs during the late nineteenth century and proved to be a critical precursor to the cultivation of forest trees on an industrial scale, since any successful industrial planting program would need to match seed sources of desirable genotypes in breeding programs with the environmental conditions under which the seeds (and later seedlings) would be grown (Munger and Morris 1936; Zobel and Jett 1995; Morgenstern 1996).

Figure 1. The approximate range of coastal Douglas-fir forests in the United States. *Source*: U.S. Department of Agriculture Forest Service and Bureau of Land Management (1994).

More than ninety years after Munger's arrival, the Pacific Slope forest industry, with the aid of forest science, has moved from mining the accumulated natural capital of the region's vast old-growth forests to the industrial cultivation of forest trees, including systematic intensification and rationalization of their growth. Under the auspices of contemporary industrial tree improvement,[4] a network of private firms, public agencies, and university scientists has undertaken the production of genetically "improved" seed and seedlings on behalf of most of the major forest-products firms operating in the region, generating sufficient replanting stock to meeting the needs of industrial Douglas-fir reforestation along the Pacific Slope. Most recently, genetically engineered varieties of hybrid cottonwoods intended specifically for deployment in fiber farms serving regional pulp and paper facilities have emerged from this same network of public and private science. Thus, in a very real sense, the emergence of genetic engineering in Pacific Slope forestry has roots in the work started by Munger ninety years ago.

This shift from extraction to cultivation in forestry involves targeting and transforming the reproductive biology of trees as a source of industrial productivity, leading to a greater degree of entanglement between biophysical nature on the one hand and capital on the other. Viewed through this lens, nature is increasingly made (or, more accurately, remade), not found: in Neil Smith's (1984) jarringly prescient framing, it is "socially produced" by industry and science. In the process, nature is converted—however unevenly—into a form of capital and commodity. The clearest evidence of these tendencies, both in technological terms and in terms of property rights, is apparent in the application of new biotechnologies in forestry, particularly in the prospect of proprietary, genetically engineered (GE) trees being introduced into commercial forestry.

In this article, I evaluate the historical political economy of Pacific Slope tree improvement as an avenue by which nature is socially produced (Smith 1984; Castree 1995), "capitalized" in the very material sense of the term (Escobar 1996; O'Connor 1998) as a response to the declining availability of old-growth forests in the region. I present Pacific Slope tree improvement as a case study of the shifting interface between industry and science on the one hand and biophysical nature on the other. Increasingly, capital circulates less and less *around* nature and more and more *through* it (Kloppenburg 1988; Boyd, Prudham, and Schurman 2001), and biological productivity—in particular, biological *time* (Adam 1998, 2000)—becomes the object of accumulation strategies, as the forest industry and forestry science together enlist the reproductive biology of forest trees to the project of growing timber bigger, "better," and faster. In short, the tree-improvement project demonstrates what William Boyd, Scott Prudham, and Rachel Schurman (2001) have theorized as a shift from the formal to real subsumption of nature by capital.

However, though clearly propelled by the liquidation of old growth, tree improvement is by no means simply a story of the Promethean conquest of nature by capital or "the market." Rather, the historical political economy of Pacific Slope tree improvement points to the interface between competitive, private firms and the forest resources on which they rely as it is mediated by scientific and state institutions collaborating and cooperating in the project of taking hold of and augmenting the biological basis of forest productivity. Applied and research aspects of tree improvement in the U.S. Pacific Northwest share a marked reliance on co-operative forms of institutional organization. This includes largely informal and communal property regimes governing information and techniques as well as plant genetic material (including both parent stock and improved tree varieties). Moreover, tree improvement on the Pacific Slope, particularly in research, has relied heavily on state science, including connections with regional, publicly supported universities and federal and local state agencies. These dimensions of tree improvement are significant given the heretofore-general absence of more proprietary tree-improvement efforts in the region (with one notable exception—see below). The strategies entailed by various institutional networks and specific actors, I argue, represent approaches to confronting specific biological "problems" and impediments of various kinds endemic to the tree-improvement project. These problems include reproductive delays, barriers to mass propagation of certain species of improved forest trees (including Douglas fir), slow maturation rates, and breeding zones fragmented by provenance concerns. All of these indicate ways in which biophysical nature, while targeted and transformed by the twin pressures of science and capital, is at the same time inscribed into the very institutional economy of nature's social production. Moreover, by this same logic, the tree-improvement story indicates that the organization of nature's social production is not institutionally static; rather, it unfolds, changing in response to new opportunities and constraints emerging from a dialectical conversation between social and environmental change (Harvey 1996). In this instance, more and more intensive commercial intervention into the reproductive biology of Douglas fir and other commercial species, reinforced by new forms of property rights over life forms, points toward a more fully commodified nature, with all manner of attendant social and environmental contradictions.

I begin with a brief discussion of recent literature on nature's reinsertion into social inquiry, and the specific question of resource limits and biophysical constraints on human geographies. The next section examines the specific biological challenges and obstacles to the industrialization of forest-tree growth, issues that have helped shape the morphology of nature's real subsumption via industrial tree improvement. Subsequently, I discuss the regional context, tracing more than fifty years between Munger's experimental work and the commencement of operational Douglas-fir tree improvement in the 1950s and 1960s. I then review developments in the early 1980s, when tree improvement became more institutionally tied to public science through silvicultural research co-operatives at state universities in the region. I step back from the region briefly in order to point to a more general preponderance of co-operative institutions and state science in American forestry, arguing that these broader tendencies reinforce the significance of forestry's "nature-centered" character. In the last section of the article, I discuss tendencies toward the commodification of improved trees coincident with the emergence of forestry biotechnology, including genetic engineering. I stress that the "success" of this project is contingent on state and broader social sanction for commercial biotechnology, and ultimately on the attendant environmental and social implications of trees socially produced using the new biotechnologies.

The article is based on research conducted over the period from 1996 to 1999 as part of a larger project examining the sweep of transition from old-growth to young-growth forestry in Oregon during approximately the last 150 years (Prudham 1999, forthcoming). Research conducted specifically on tree improvement involved a combination of archival and contemporary document analysis on industrial forestry and forestry research and approximately twenty in-depth, semistructured key-informant interviews with individuals having expertise in tree improvement, forest genetics, and plantation forestry. Informants included university professors and professional foresters working with both public and private institutions.[5] All interviews were taped. Disclosure of the identities of key informants in any published work resulting from the research is prohibited by mutual agreement between the author and the interviewees, as required by the University of California-Berkeley's protocol for ethics and research involving human subjects.

Nature's Limits

The question of nature's "limits" to industrial growth and expansion has long been a preoccupation of social science. Under classical political economy, key observers such as Malthus, Ricardo, and later Mill were generally pessimistic about the prospects for economic growth and development to overcome the limits of nature (Barry 1999). However, the combination of Marx's generally Promethean faith in science and industrial dynamism (see Schmidt 1971; Harvey 1996) with neoclassical market triumphalism (e.g., Barnett and Morse 1963) presented a united front for some time against the idea of environment as constraint, drowning out dissenters, notably Karl Polanyi (1944). Sadly, human geographers largely participated for a considerable time in the resulting, widespread, and conspicuous silence on relations between nature and society (see, e.g., FitzSimmons 1989; Hanson 1999; Bridge 2000, 2001). Only somewhat recently, coincident with rapid environmental change at local, regional, and global levels, has this front begun to weaken, inspiring a debate about the "limits to growth" (Meadows and Club of Rome 1972; Harvey 1974) and re-engagement with interconnections among social institutions, politics, cultures, and economies on the one hand and the dynamics of environmental change on the other (e.g., Watts 1983; Blaikie and Brookfield 1987; FitzSimmons 1989; Lonergan 1993; Peet and Watts 1993; Davis 1998; Liverman 1999).

In the development of an incipient ecological political economy, recent work has grappled with how to reinsert environmental change and its politics without lapsing "into some form of environmental determinism . . . or a damaging material pessimism" (Harvey 1996, 193). Reflecting these concerns, considerable recent critical scholarship on society-nature questions has been preoccupied with the politics of knowledge claims, or what might be understood as the socially constructed nature of nature (see, e.g., Demeritt 1994; Willems-Braun 1997; Robbins 2000).

While important, emphasis on social construction—or production, for that matter—runs the risk of relegating material nature to a role as passive witness to socially determined geographies (Castree 1995; Bridge 2001; see also Demeritt 2001a). This, in turn, has sparked interest in (among other responses) some reconciliation within an historical materialism of political ecological change. Indeed, despite his predilection for metanarratives of capitalist transformation (begging the question as to how nature's difference can actually matter at all), David Harvey (1996), argues that it is the essence of historical materialism to embrace the intertwining of nature and culture through historical analyses of particular ecological transformations. Enrique Leff (1995, 14) expresses a similar sentiment: "[T]he availability of nonbiotic resources and the conditions for biological reproduction of different ecosystems affect the form and appropriation of natural resources. These factors also establish potentials and set certain limits to the expansion, reproduction, and sustainability of capital. These, then, are the reasons to insist on thinking about *how ecological processes are inscribed in the dynamics of capital*" (emphasis added).

A productive avenue for pursuing such inscriptions is via the development of a theory of ecological crisis, whereby the destruction of particular natures under capitalism results not in absolute or final "limits," but instead in ongoing political struggle over the social (re)production of new natures, both for the purposes of renewed accumulation and for broader societal goals. Ecological crises of this sort may take the form of natural-resource depletion or of degradation of the capacity of environmental systems to absorb the various waste products of economic activities, and they are subject to all manner of contending social constructions regarding the origins and implications of environmental change. The best-known excurses on ecological crisis tendencies is still James O'Connor's (1988, 1998), and O'Connor draws on and extends Polanyi's (1944) thesis that nature is one of three categories of fictitious commodity, never truly made by capital nor wholly allocated by market forces and subject to conflicting demands between an increasingly self-regulating market and wider societal imperatives. In fact, O'Connor (1998, 164) specifically—albeit briefly—cites conversion from old-growth to plantation forestry as an example of how nature is first degraded as a condition of capitalist production and then "capitalized" by "the increased penetration of capital into the conditions of production (e.g., trees produced on plantations)." However, at the same time, he strongly implies a unidirectional impulse toward increasingly socialist production of nature via the state. Yet, if industrial forestry in its myriad forms—including Pacific Northwest tree improvement—provides any indication, political-economic responses to the "underproduction" of nature as a condition of accumulation are ultimately contingent and include the possibility of more full-blown commodification of nature.

Nevertheless, O'Connor's thesis remains singular,[6] because it draws the ecological consequences of nature's material transformation under capitalism into the political-economic mainstream. In this sense, the exhaustion of various natural resources in particular places and particular times may be located against the backdrop of the dynamics of capitalist expansion (Castree 1997). It bears mentioning, however—reflecting again the sentiments of Leff (1995; see above) and others—that ideas of limits or constraints must be understood as both general *and* specific. O'Connor himself specifically precludes a direct or objective translation of ecological transformations into culture or politics. Rather, it is exactly political struggles over meaning and societal responses that make for crises, including defining whether and how the capitalization of nature may preclude a full-blown political crisis. This perspective reflects not only the importance of uneven political-ecological space, but also the ways in which resource exhaustion or environmental pollution may become important influences on and opportunities for innovation and restructuring processes, depending on political, institutional, and technological factors that are also historically and geographically specific.

Thus, numerous observers have attempted to develop more mesolevel concepts to understand how biophysical nature shapes and constrains social action in specific historical and geographical circumstances. From Ted Benton (1989) comes the idea of "ecoregulation," under which the application of labor and machinery is shaped and constrained by natural processes, particularly in certain nature-centered sectors (empirically, see also Prudham 2002). David Demeritt (1998), also grappling with social knowledge construction and the "matter" of nature, draws on science and technology studies—notably the writings of Bruno Latour and Donna Haraway—to argue for a view of the natural and the social as locked in an embrace of "conjoined materiality." One line of thinking in agrarian political economy has long emphasized the significance of agriculture's nature-based character as an influence on agrarian institutions and social relations, including the morphology of specific commodity chains (Goodman, Sorj, and Wilkinson 1987; Kautsky 1988; Mann 1990; Goodman and Redclift 1991; Page 1996; Henderson 1998).

Most recently, Boyd, Prudham, and Schurman (2001) have developed a framework for understanding the different ways in which nature not only constrains but is also targeted and mobilized in renewable versus nonrenewable resource sectors. We point to increasingly intensive industrial cultivation systems in forestry, aquaculture, and agriculture as examples of capital's real subsumption of biological growth as a strategy for expanded accumulation. In this manner, "limits" are progressively transformed by industrial innovation. By no means is "final" victory over nature achieved in any sense of the phrase (if indeed such a framing could ever make sense). As we note in outlining our framework, all manner of natural dynamics remain, and capital's incursion into reproductive biology is never complete, not least because of the *necessarily* partial logic of nature's commodification (i.e., socially produced nature, though increasingly manipulated, still relies on ecological inputs of various kinds). This suggests, not a narrative of environmental *limits*, but one of environmental *logic*. Approached in this way, and drawing on ecology as a study of relationships, theories of ecological contradiction need to explore the ecology of capitalism as a set of dynamic relationships.

These observations are central, but with few exceptions (e.g., Kloppenburg 1988; Bridge 2000; Boyd 2001; Prudham 2002) they remain largely abstract. My point of departure is that notions of ecological contradiction, conjoined materiality, ecoregulation, and the real subsumption of nature only take on meaning when examined in historical and geographic contexts, as specific landscape forms are mobilized within particular social formations. Providing an historical example in a regional context is a central aim of this article.

Biological Obstacles to Proprietary Tree Improvement

While capital and an industry-driven state science increasingly seek to socially produce nature in plantation forestry, and tree improvement in particular, the specific biophysical dynamics and characteristics of material nature become inscribed in the social organization of these projects (Leff 1995). Some of these dynamics and characteristics are unique to Douglas fir, the Pacific Slope region's staple commercial forest tree; others are more pandemic in forest trees, as I will also discuss. Yet as a piece, they comprise an excellent example of what Boyd et al. (2001) refer to as the "problem of nature": that is, the contradiction-ridden and uneven processes by which biological nature is formally subsumed in natural resource sectors.

Consider first the issue of time, specifically biological time. Barbara Adam discusses time as a key problematic facing the industrialization and modernization of nature (Adam 1998, 2000), noting that social theory has given too little notice to the formation of distinctive "timescapes" via the collision of social and natural time under capitalist modernity. As she (2000, 137) has written specifically in relation to GE food debates, "[A] timescape analysis is not concerned to establish what time is, but rather what we do with it and how time enters our system of values." Several observers have noted the ways in which biological time presents challenges to capitalist agriculture, including, for example, seasonal crop cycles and animal gestation periods that can produce "built-in" delays in the turnover of capital (Mann 1990; Goodman and Redclift 1991). Such challenges do not necessarily represent dead ends, however; instead, they may comprise the focus of concerted attempts by capital, aided in various ways by science (state-supported and otherwise) to take hold of and transform biological time, or at the very least, to incorporate particular delays and vulnerabilities into the circuits of capital accumulation. Examples include all manner of intensive breeding and cultivation schemes aimed at industrializing organisms, from fish to fowl (see, e.g., Boyd 2001), as well as the formation of distinct agrarian credit systems (Henderson 1998).

While taking hold of and compressing biological time is one of the central goals of tree improvement insofar as the endeavor selects for accelerated growth (a key goal of all commercial tree improvement), at the same time, the collision of social and biological time in tree improvement presents major problems, not least because of delays and lags larger than anything encountered in agriculture. With a commercial rotation age along the Pacific coast of roughly sixty to eighty years, Douglas fir is particularly problematic, making socially produced Douglas fir a distinct form of fixed capital. The significance of such long growing times is exacerbated by uncertainties regarding returns on investment in tree improvement, not least because of the sheer novelty of the undertaking. This is reflected, for example, in research contemporaneous with or subsequent to the commencement of industrial tree-improvement efforts along the Pacific Slope on fundamental questions, such as the degree to which growth rates in Douglas fir are genetically controlled (Namkoong, Usanis, and Silen 1972) and thus accessible by tree improvement.[7] Observed results from tree improvement have tended to reinforce expectations of significant gains (height and volume) to be realized at rotation age, perhaps on the order of 20 percent (Jayawickrama 2001). However, despite substantial research on early identification of superior growth (e.g., Copes, Sorensen, and Silen 1969; Ritters 1986; Pacific Northwest Tree Improvement Research Co-operative 1996), uncertainty remains regarding the correspondence between observed traits in young trees and the realization of gains at commercial maturity (St. Clair 1993), and, as the cliché goes, only time will tell.

Yet time is also an issue and of the essence in breeding. Delays are introduced in waiting for seedlings to grow large enough to provide a basis for their evaluation, while retained varieties must be allowed to reach sexual maturity before they can be crossed with other selected varieties to produce improved seed: Douglas fir, under normal conditions, take twelve to fifteen years to produce flowers. Though this has since been ameliorated by techniques to stimulate early flowering (Ching, Ching, and Lavender 1973; Hagenstein 1973), it was a key rationale for the development of tree-improvement techniques employing immediate collection of commercial quantities of seed from selected parent trees; waiting to cross the progeny of such trees in "full-sib crosses" was beyond the time horizons of participating firms, particularly in the absence of secure knowledge of the expected gains from tree improvement (Silen and Copes 1972; Silen and Wheat 1979).

Time is not the only problem, however. Consider the need to regulate gene flow in the production of commercially improved varieties. Controlled breeding in the production of crosses can be highly problematic, with significant implications in the event that it fails. Male and female flowers are ubiquitous on conifers in general, including Douglas fir, creating large numbers of possible cross-fertilization points. Combined with the physical architecture of the trees, this makes manual fertilization both difficult and laborious (Ching 1960).[8] At the same time, seed orchards used to produce improved seed from selected crosses tend to be located in forest settings among "wild" trees, and the risk of uncontrolled cross-pollination has been a pervasive problem (Silen and Copes 1972; Adams et al. 1997).

In addition, consider biological obstacles to economies of scale in plant-breeding. Like many conifers (redwood [*Sequoia sempervirens*] being an important exception to this rule), Douglas fir has proven difficult to propagate from cuttings and shoots. Yet mass production is absolutely essential to justifying greater investments in tree improvement, since investment in improved individuals that may only be produced one at a time is unlikely to be profitable. Despite recent developments using novel bioprocessing techniques (see below), this has been a persistent issue affecting Douglas-fir tree improvement.

Finally, provenance itself presents a major challenge, particularly along the Pacific Slope. Numerous traits—including, for example, drought and cold tolerance (Ferrell and Woodward 1966)—have evolved among populations of Douglas fir based on the wide range of the species and the extreme variations in climate across the topographically uneven areas of coastal Oregon and Washington. To ensure that like breeds with like, tree improvement makes use of distinct seed-source zones. The determination of such zones, at least initially, was as much guesswork as science, and it has remained a source of debate among forest geneticists from the establishment of Douglas-fir tree improvement on an industrial scale (see, e.g., Sorensen 1983) right up to the present (key informant interview, 19 December 1997, Centralia, WA). But a cautious approach developed by Roy Silen, the architect of co-operative Douglas-fir tree improvement, led to the creation of seventy-five separate breeding zones (Silen and Wheat 1979; Bordelon 1988), forty-nine of which are in western Oregon alone (see Figure 2). These breeding zones create logistical challenges in tree improvement by restricting the area from which genotypes may be selected and crossed while at the same time typically spanning multiple land ownerships. To achieve the greatest possible gains within each zone, different landowners, including public agencies and private firms, must share genetic resources.

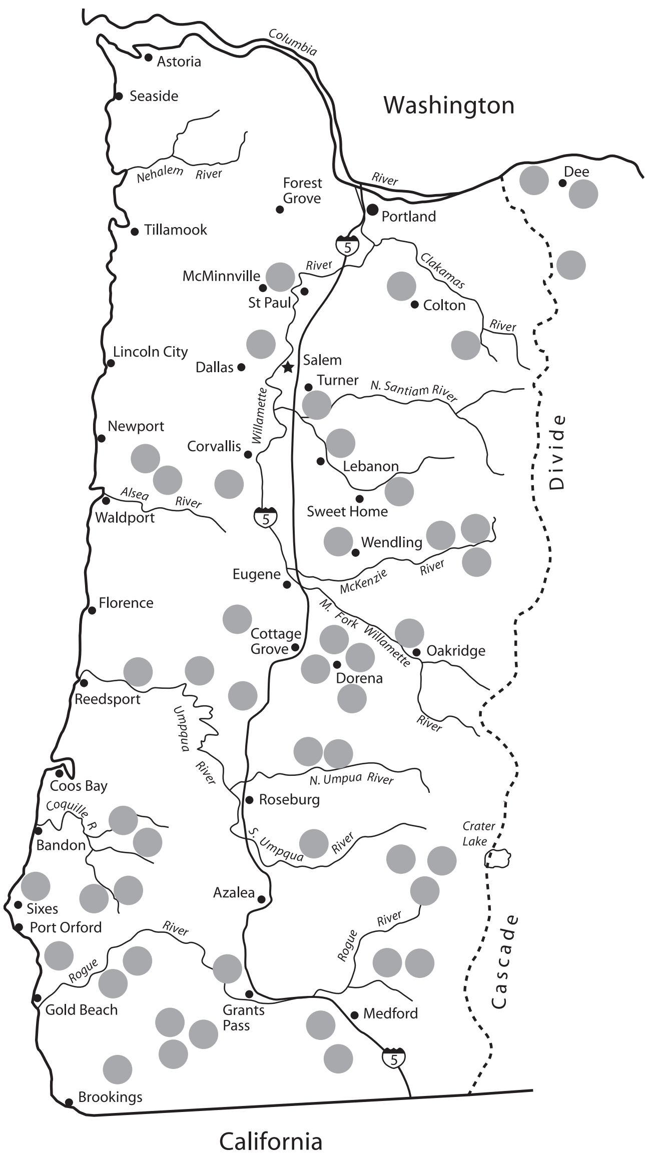

Figure 2. Douglas-fir seed zones used by the Northwest Tree Improvement Co-operative. *Source*: Adapted from Bordelon (1988).

For all of these reasons, despite the fact that the improved trees represent the next generation of wood fiber (and thus comprise a potential source of competition between firms), firms in the Pacific Slope region have tended to co-operate extensively on several levels, including sharing genetic resources as common property. This extensive co-operation, along with the central involvement of state-supported science, reflects a common ethos uniting factions of forestry science and capital around taming—or as two forest scientists put it (Cheng and Voqui 1977, 307), "domesticating"—wild trees for the purposes of more efficient commodity production. At the same time, however, it also indicates the biological challenges of the undertaking and thus the reluctance of firms (on the whole, and as of yet) to embrace this project as an exclusive and proprietary undertaking—that is, as a basis of capitalist competition. Reflecting on thirteen years of co-operative Douglas-fir tree improvement using Silen's "progressive system," and noting many of the technical problems, uncertainties, and delays endemic to the undertaking, Silen and Joe Wheat (1979, 81), note simply that "Under no circumstances could any of the owners have then carried such a comprehensive program alone." In short, this is an example of exactly the sort of "inscription of ecological processes" onto the morphology of nature's appropriation envisioned by Leff (1995).

Co-operative Tree Improvement, 1956–1995

Delays

Although Munger began his research in 1913, it was not until the mid-1950s that systematic tree-improvement research commenced in the Northwest. This substantial delay can be attributed in some measure to the historical geography of the forest sector in the United States, an industry for which the spatial fix (Harvey 1982) involved an incessant search for new sources of raw material, manifest as a march from Northeast to Midwest and Southeast and finally Northwest (Williams 1989). Once the industry arrived on the Pacific Slope, liquidation of old-growth forest resources proceeded as it had elsewhere. In Oregon, the ecological crisis associated with the end of the era of old growth is widely associated with the U.S. Fish and Wildlife Service's listing of the northern spotted owl as a threatened species in June 1990 (Franzsreb 1993; Marcot and Thomas 1997). However, it is more accurate to describe this crisis as having two distinct historical demarcations (see Figure 3), the second of which coincided with the listing of the spotted owl.

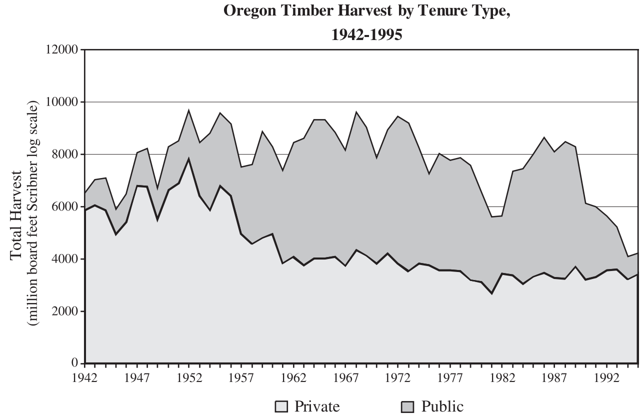

Figure 3. Oregon Timber harvest by tenure type. *Source*: Oregon Department of Forestry, annual reports (1997). Salem, OR.

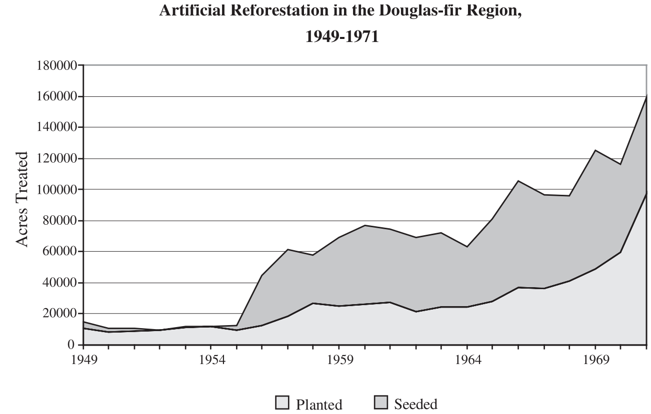

Figure 4. Artificial reforestation in the Douglas fir region, 1949–1971. *Source*: Hagenstein (1973).

The first demarcation occurred during the late 1940s and early 1950s, as declining private inventories of old growth and fears of an impending timber famine prompted significant political, economic, and ecological shifts in American forestry. These changes included a dramatic expansion of federal timber-sale programs from public lands and the adoption of scientific principles of sustained-yield forest management in federal and state forest policy (Robbins 1982, 1987; Hirt 1994; Prudham 1998; Rajala 1998; Demeritt 2001b). As early as the 1940s, concern was mounting regarding the prospects of timber depletion on western Oregon lands held by the largest industrial landowners. It was in this context that Oregon passed the Oregon Forest Conservation Act of 1941, the nation's first set of legislated forest practice regulations (Robbins 1982; Prudham 1999), reflecting and reinforcing pressure on industry to address the reproduction of nature on cut-over lands. Not coincidentally, it was also in 1941 that Weyerhaeuser established the nation's very first industrial tree farm near Grays Harbor, Washington. Later that same year, under the direction of William Greeley, the West Coast Lumbermen's Association established a co-operative nonprofit nursery—the region's first—to supply five million seedling trees per year for reforestation purposes. Seven years later, the Industrial Forestry Association (IFA) was formed as a collaborative effort among large industrial operators to coordinate Douglas-fir nursery and planting activities in the region (Hagenstein 1973). All of these developments underpinned a rapid expansion of regional industrial reforestation between the mid-1950s and 1970 (see Figure 4), overwhelmingly focused on regenerating the region's staple tree, Douglas fir (see Table 1).

In the early years, Douglas-fir seeding and planting efforts made use of unimproved stock: that is, they relied exclusively on seeds collected from wild forest trees, without any attempt at systematic tree-breeding. This occurred despite the foundation for tree improvement laid by Munger in the early century and a European lineage of research and experimentation on forest- and fruit-tree genetic variation and breeding dating from the eighteenth century and widely established by the mid-nineteenth (Zobel 1981; Morgenstern 1996). This points to a second source of delay (in addition to the rate of old-growth liquidation): namely, the gradual rate at which scientific understanding of forest genetics—including issues surrounding provenance—was accumulated and made commercially useful. Relatively "basic" research on Douglas-fir provenance and breeding, for instance, continued well into the 1960s (e.g., Ferrell and Woodward 1966; Silen and Copes 1972). Moreover, problems emerged in translating research into operational tree-breeding. This proved particularly true for work with species resistant to clonal propagation, as are many commercially important forest conifer species, including the Douglas fir. Without easy cloning options, producing improved trees one at a time meant that tree improvement

Table 1. Softwood Timber Harvest, Western Oregon, 1995

Species	Harvest (Thousand Board Feet Scribner)
Douglas fir	1,887,975
Hemlock	297,892
True fir	101,958
Cedar	47,935
Pine	21,047
Spruce	62,474
Other	127,273
Total softwoods	2,546,554

Source: Oregon Department of Forestry (1997).

was largely an arena for research, not commercial development.

This "problem" was addressed through Syrach Larsen's research in Denmark during the 1930s. Larsen pioneered the grafting of "plus" or "elite" tree scions (cuttings) onto established host root-stocks for the purposes of controlled experimentation and breeding in seed orchards. The trees resulting from these grafts expressed the genotype of the scion, not the root stock, and thus Larsen was able to create orchards of selected or plus tree-breeding stock for the purposes of cross-pollination and the production of improved seed stock (Larsen 1956; Toda 1981). Significantly, however, this system of producing large quantities of improved seed would only work in the long run using cross-pollination rather than vegetative propagation. In effect, the "natural" obstacle to mass propagation of desirable genotypes spelled the end—for the time being, at least—of commercial tree improvement based on hybrid varieties, the darling of early experimental forest-tree improvement (Righter 1946).

The significance of this turn is not merely of biological interest. Rather, as Jack Kloppenburg (1988) emphasizes in tracing the political economy of American corn-breeding, hybridization offers a mechanism for protecting improved varieties as proprietary inventions, since hybrid crosses do not "breed true": that is, saved seed will not result in the regeneration of the genotype beyond the first generation. While this strategy became a productive route by which agroindustry could take hold of plants as exclusive commodities well before contemporary genetic engineering and attendant new possibilities in the realm of intellectual property rights, the same avenue was effectively blocked in commercial forest-tree improvement until quite recently with the advent of new techniques in clonal propagation and tissue culture (Cheng and Voqui 1977; Baker 1992; Pierik and Prakash 1993).

Experimental Tree Improvement

The legacy of Larsen's research and the hybridization problem is clearly apparent in the emergence of experimental Douglas-fir tree improvement. Having spearheaded the establishment and certification of numerous industrial tree farms, in 1954 the IFA hired the Pacific Slope's first industrial forest geneticist, John W. Duffield, in order to coordinate an experimental program of Douglas-fir tree improvement involving multiple landowners (Zobel 1981). Duffield obtained his Ph.D. from the University of California-Berkeley and had worked at the U.S. Forest Service's Institute for Forest Genetics in Albany California, which by the 1930s had become a leading center for research on forest-tree improvement and where considerable early research focused on tree improvement through hybridizing conifer (particularly pine) species (Righter 1946). Yet in 1956, when the IFA invested U.S.$40,000 in a research facility in Nisqually, Washington, Duffield led a program based, not on hybrids, but on Larsen's model, using seed produced from crosses of grafted parent stock in a seed orchard. Participating firms selected plus trees, collected scions, and used grafts to establish three IFA seed orchards based on the Larsen approach, two located in western Oregon and one in western Washington (Silen and Copes 1972; Hagenstein 1973).

Applied, Co-operative Douglas-Fir Tree Improvement

Duffield's IFA program evolved into the region's first applied tree-improvement co-operative, established in Vernonia, Oregon in 1967. Although it was a private-sector initiative involving collaboration between three industrial competitors (Crown Zellerbach, Longview Fiber, and International Paper), the Vernonia co-operative also relied on scientific commitments by the local and federal state via the involvement of the Oregon State Department of Forestry and the U.S. Forest Service (Jayawickrama 2001). In particular, the Vernonia co-op was assisted by Silen, of the U.S. Forest Service's Forest Science Laboratory at Oregon State University, and his "progressive system" of tree improvement (Silen 1966; Silen and Wheat 1979).[9] Like Duffield's experimental program, Silen's system relied on sexually reproduced and reproductive parent and seed stock, as opposed to hybrid stock. Unlike the IFA experimental program, however, the Vernonia co-op eliminated grafting and seed orchards from the first generation of seed production. Early experiments with Douglas-fir tree improvement suffered from widespread failures in the viability of Douglas-fir grafts (Silen and Copes 1972). At the same time, firms were concerned with the delays involved in testing selected varieties, since grafted parent stock had to be allowed to reach sexual maturity before producing seed. Silen reasoned that genetic gains from wild, wind-pollinated seed collected from the forest could match gains from seed in first-generation seed orchard crosses, and could save time as well. Reflecting his influence, the Vernonia co-op collected seed for commercial reforestation directly from phenotypes of forest trees. Before seed was used in reforestation, tests of progeny were conducted to more carefully refine the selection process. Seed orchards came into play only in producing a second generation of seed, relying on parent stock planted from seed, not regenerated from grafts (Silen and Wheat 1979; Bordelon 1988).

As more and more firms with land in western Oregon and Washington expressed interest, Silen worked with Duffield's successor at the IFA, Joe Wheat, to expand the Vernonia co-op into a network of cooperative tree improvement forming the backbone of Douglas-fir tree improvement in the region. By 1979, the network had grown to include thirty-three companies and approximately 2.5 million hectares of timberlands distributed across nineteen local co-operatives involving both public and private forest-land owners (Jayawickrama 2001). This network was renamed the Northwest Tree Improvement Co-operative (NWTIC) in 1985, and by 2001 it featured a membership of thirty public and private members (Jayawickrama 2001), with seventy-five separate breeding zones and twenty-two local tree-improvement co-ops (key informant interview, 19 December 1997, Centralia, WA).

The fragmentation evident in the proliferation of local co-ops and distinct breeding zones emerged from Silen's design to assure that like bred with like (provenance). According to his specifications, breeding zones were defined initially as ecologically similar areas on the order of 60,000 ha, with elevation ranges of less than 300 meters (Silen and Wheat 1979), although the size of breeding zones has since expanded somewhat (key informant interview, 19 December 1997, Centralia, WA). Firms with lands in each breeding zone share co-operatively in the selection and testing of potential parent trees for seed orchards in order to capture genetic gain across the maximum area, pooling their genetic resources within each zone. Based on this local, co-operative model, the NWTIC was able to meet 80 percent of the seed requirements of co-op members in the region by the late 1980s (Bordelon 1988), and has produced enough improved seed to reforest in excess of 3 million hectares of forest land with socially produced trees (St. Clair 1993). The network has become by far the single greatest source of improved Douglas-fir varieties. It includes all of the major industrial landowners in the Douglas-fir region, with the lone exception of Weyerhaeuser, whose non-participation I discuss below.

Co-operative Research and "Public" Science

Co-operative tendencies and the high profile of public forestry science in the social production of Pacific Slope forests have been reinforced since 1980 by the emergence of co-operative silvicultural research institutions housed at state universities in the Pacific Slope region, including Oregon State University in Corvallis, the University of Washington in Seattle, and Washington State University in Pullman. Since the first such co-operative was established in 1979 (key informant interview, 17 September 1997, Corvallis, OR), they have become a key avenue for public-private co-operation involving multiple private firms, state agencies, and university scientists. Such co-ops not only undertake tree-improvement research and development, but also tackle issues such as stand management (e.g., chemical applications, thinning, etc.) and nursery technology development. These silvicultural co-operatives have become vital to the social (re)production of timber resources in the region, inasmuch as they assume responsibility for much of the scientific research underlying intensive plantation forestry.

Silvicultural research co-operatives vary somewhat in the ways in which they are organized, but they also exhibit some key common characteristics. These include co-operative relations between private and public members, extensive assistance in funding and staffing from the universities, and largely informal management of innovations and information, including (until recently) common and relatively informal property regimes over plant varieties (key informant interviews: 3 September 1997, Corvallis, OR; 17 September 1997, Corvallis, OR; 14 November 1997, Corvallis, OR). Co-ops are formed on the basis of partnerships involving members drawn from the ranks of private forest-products companies and timberland owners as well as public forest-management agencies, including, for example, the Forest Service, the Bureau of Land Management, and state forestry departments. Other members may also include commercial interests, such as nurseries, whose business draws them to particular co-ops.

The co-ops are individually led by one or more academic scientists, typically a forestry professor in one of the region's main state universities. These researchers manage the co-ops and undertake much of the actual research, along with technicians and graduate students. Experiments are either carried out under laboratory conditions or developed using experimental plots on land belonging either to the host university or to co-op members (or both) (key informant interview, 14 November 1997, Corvallis, OR). Data and the results of research are made available to all members, although data from individual plots on private land is not always available in raw form within the co-op. Co-ops also publish annual reports describing research and results, along with personnel, membership, and budget information. While data are not typically released to non-co-op members, annual reports are in the public domain.

Funding for these programs is drawn from a combination of annual member dues (in fixed amounts or prorated according to their acreage), university contributions of facilities and equipment, staff, and direct financial inputs, and external grants and contracts from agencies such as the National Science Foundation and the U.S. Department of Agriculture. In exchange for their dues, member firms are given a formal role in co-op governance, including the establishment and periodic adjustment of the co-op's research agenda. Decision making is typically accomplished by means of periodic meetings at which members and co-op staff debate and vote on research direction. This aspect of co-op governance is significant insofar as it involves the appropriation of state-supported science by private forest-products companies and landowners. It should come as no surprise in this respect that research undertaken by the co-ops tends toward a heavily commercial orientation, primarily toward the more efficient and productive growth of industrial fiber—that is, harnessing, taming, domesticating, and subordinating the biological underpinnings of forest reproduction to the dictates of capital.

In tree improvement, the most important co-op is the Pacific Northwest Tree Improvement Research Co-operative (PNWTIRC) at Oregon State. The PNWTIRC was founded in 1983 to provide research support for the network of Douglas-fir tree improvement conducted under the NWTIC. That is, while the NWTIC manages actual co-operative tree-improvement activities among members, the PNWTIRC acts as its research arm, providing technical assistance based on ongoing research programs (Jayawickrama 2001). The organization's membership is composed of some of the largest integrated forest-products companies in the region, together with public forest land-management agencies (Pacific Northwest Tree Improvement Research Co-operative 1996).

The research undertaken by the PNWTIRC provides a good indication of the generally commercial orientation of co-operative research—again, no surprise, given the membership, funding, and governance structures of such co-ops. For example, the PNWTIRC places major emphasis on the early selection of Douglas fir for cold and drought resistance, identifying the genetic basis of these traits and the relationship between these traits and growth characteristics with more direct commercial advantages (e.g., wood density) (Pacific Northwest Tree Improvement Research Co-operative 1996). Emphasis on these issues is driven by the desire to breed trees across wider geographic ranges in order to increase the economic efficiency of tree improvement and to continue to capture genetic gain in successive generations of improved trees. The co-op is also working on techniques to control more tightly the lineage of crosses produced in the seed orchards (key informant interview, 17 November 1997, Corvallis, OR), motivated by uncertainties in gene flow introduced by relying on open wind-pollination techniques (Silen and Copes 1972; Adams et al. 1997).

High-Yield Forestry

Overall, then, Douglas-fir tree improvement in the Pacific Slope to date has been characterized by extensive co-operation among private firms and public agencies, while state-supported and co-operative science co-ordinated by academics at major research universities has taken on the lion's share of research in support of industrial tree-improvement programs. There is, however, an important exception to this prevailing organization and division of labor. In 1969, Weyerhaeuser began a program the company called High-Yield Forestry, an approach to intensive reforestation seeking to match chemical inputs and other intensive management techniques with the use of improved seed. By the early 1970s, Weyerhaeuser employed approximately thirty Ph.D. forest geneticists working at the company's research facility in Centralia, Washington (key informant interview, 19 December 1997, Centralia, WA).

Like other forestry firms embarking on tree improvement, Weyerhaeuser faced uncertainty and delays. However, the firm aggressively pursued progeny testing and applied tree improvement in parallel, not in sequence, with company geneticists reasoning that a tree-improvement program could do no worse on average than wild breeding (key informant interview, 19 December 1997, Centralia, WA). Relatively quickly, Weyerhaeuser was able to meet all of its reforestation needs in western Oregon and Washington with industrially produced varieties of improved seed. The company predicts a first harvest from trees planted under the High-Yield program sometime in the next decade (Virgin 1997).

Aside from the scale and ambition of Weyerhaeuser's program, High-Yield Forestry stands out because it is a much more proprietary form of intensive forestry research and development than is typical of the region's other firms and public agencies. This is not to say that Weyerhaeuser avoids involvement in the research co-operatives. Indeed, most of the co-ops with research interests applicable to Weyerhaeuser's lands and operations do claim the company as a member. But the High-Yield Forestry program stands out as a proprietary effort in a region and an industry characterized by more co-operative approaches—for now, at least.

Yet I argue that Weyerhaeuser is the exception that proves the rule. Weyerhaeuser is by far the largest landowning firm in the region, with approximately two million acres of timberlands (Weyerhaeuser Company 1999). More than half this land was purchased from the

Burlington Northern Railroad in two transactions between December 1899 and August 1901 (Twining 1994). Because of the way they were obtained, these lands are more contiguous than most industrial holdings. Also, being primarily located in western Washington, these lands are generally less topographically uneven, with breeding zones generally larger than those of western Oregon. Large areas of top-quality timberland allow for greater economies of scale underlying investment in industrial tree improvement, enhanced by more homogeneous land in contiguous configurations that cut down on the number of breeding zones and thus the proliferation of seed orchards.

Tendencies in the Political Economy of American Forestry

As I have argued thus far, co-operative, publicly supported tree improvement provides a strategy for confronting biological constraints that dissuade more aggressive, proprietary forms of capital investment in the social reproduction of forest trees. It would be disingenuous, however, to suggest that these issues are unique to the Pacific Slope, although particular biological challenges and institutional configurations have distinct regional flavors. Indeed, although anxieties about timber famine and the exhaustion of old-growth forests are longstanding in the discourse and politics of American forestry (Greeley 1925; Robbins 1982; Demeritt 2001b), proprietary, private-sector enthusiasm for forestry research has been and remains relatively tepid in the United States; the state and co-operative institutions have assumed a disproportionate responsibility for the intensification and rationalization of forest growth. These broader patterns reinforce regional patterns, and suggest that forestry's biophysically centered character is a key influence on the political economy of American forestry more generally. I cannot exhaustively document these tendencies in this article, and others have already done so in significant respects (e.g., see Robbins 1982, 1985; Rajala 1998). A brief discussion, however, is warranted.

Consider, for instance, that according to the National Science Foundation (1996), private research and development expenditures in the lumber, wood-products, and furniture industries averaged 0.7 percent of sales from 1984 through 1994, while expenditures in the paper and allied products industry averaged 0.9 percent of sales over the same period. These figures are quite low compared to an overall manufacturing industry average of about 3.1 percent of sales during the same period (see Table 2). Moreover, as Paul Ellefson (1995) notes, private research

Table 2. Company and Other (Nonfederal) Research and Development Funds as a Percent of Net Sales in Wood-Based Industries and All Manufacturing Sectors, 1984–1994

	All Manufacturing	Lumber, Wood Products, and Furniture	Paper and Allied Products
1984	2.6	0.7	0.8
1985	3.0	0.8	0.8
1986	3.2	0.6	0.7
1987	3.1	0.6	0.6
1988	3.1	0.6	0.8
1989	3.1	0.6	0.8
1990	3.1	0.6	1.0
1991	3.2	0.9	1.1
1992	3.3	0.9	1.0
1993	3.1	0.7	1.1
1994	2.9	0.6	1.0
Average	3.1	0.7	0.9

Source: National Science Foundation (1996).

and development expenditures in the forest-products sector are heavily skewed toward investment in forest-products research, rather than forestry per se. Ellefson estimates that four or five companies (one of which is Weyerhaeuser) dominate private investment in forestry, and that overall more than 90 percent of private investment in the forest sector is oriented toward forest products research. Correspondingly, while total public support accounts for only 5 percent of all forest sector research and development expenditures, public expenditures account for about 85 percent of research funding for research in forestry per se (Ellefson 1995).

The division of labor is evident: while industry invests in commodity and process innovation, the state provides the vast majority of funds for biology-based innovation. This is underpinned by a history of federal and state funding for forestry research dating back almost one hundred years and channeled through various federal laboratories managed under the auspices of the U.S. Forest Service (e.g., the Pacific Northwest Forest and Range Experiment Station in Portland) as well as the state land-grant universities. The origins of these programs cannot be dissociated from state efforts to ensure forest reproduction in the face of industry cut-and-run tendencies, yet such public efforts have ever been propelled by a desire to perpetuate forest-commodity production (Robbins 1982, 1987; Rajala 1998; Demeritt 2001b)—that is, to reproduce nature in order to sustain capital accumulation.

In addition, co-operative institutions not unlike the PNWTIRC, many of them also housed at state-supported research universities, have comprised an essential foundation for operational and research dimensions of diverse aspects of forestry innovation in commercial forest regions across the country. While relatively little research—

academic or otherwise—has been done on such institutions, an American Forestry Council survey conducted in 1987 identified a total of fifty-one co-operative forestry institutions housed at research universities and drawing membership from a range of private firms and public agencies. North Carolina State and Oregon State are leading universities in terms of the number and size of their co-ops; other important host institutions include the University of Washington, the University of Florida, the University of Maine, Texas A&M, and Virginia Polytechnic Institute and State University. Keeping in mind a context in which more proprietary and private forms of investment in forestry have been extremely limited, the significance of these institutions should not be underestimated.

The key theme here is that while the entire purpose of industrial forestry—including tree improvement—is to intensify and rationalize forest-tree growth, it is, in fact, the biophysical challenges of doing so that have largely inspired co-operative institutional strategies, extensively assisted by state-supported science. This is reflected in the ways in which biological constraints impede—or, more accurately, dissuade—proprietary, private efforts at confronting nature's limits in the broad context of American forestry. As Ellefson (1995, 134) plainly yet unremarkably states in his review of forest-sector research and development in the United States, "[I]ndustrial forestry research efforts . . . must face the realities of long pay-back periods for investments in forestry research, high risks and uncertain consequences of research investments." That is, forestry research must confront the challenge of a reproductive biology that obeys its own laws and rhythms, twinned with scientific uncertainty regarding how these laws and rhythms may be subordinated and rationalized. In short, both regionally and in the nation more broadly, co-operative and public-private institutional configurations of tree improvement—and industrial silviculture more generally—may be understood as the key strategies by which the biological basis of forest productivity is increasingly enlisted, laying the groundwork for the real subsumption of nature.

The Tree Genetic Engineering Research Co-operative

Yet, as strategies for the exclusive appropriation and commodification of the reproductive biology of forest trees (and varieties of trees themselves), high degrees of co-operation point to serious tensions and contradictions from the standpoint of capital. Specifically, the relatively open property regimes prevailing over tree varieties and tree-improvement techniques, enabling co-operative tree-improvement efforts such as the NWTIC as well as state-supported research co-operatives, do not allow individual firms to take hold of forest-tree varieties and the biology of their reproduction as bases of proprietary competition and innovation. As yet, forest tree improvement has not witnessed what Kloppenburg (1988) describes so powerfully in the history of agricultural crop breeding (specifically corn): that is, the conversion of the reproductive biology of plants (beginning with proprietary seeds) into discrete commodities (see also Goodman, Sorj, and Wilkinson 1987).

However, as in agriculture, the advent of biotechnology may accelerate these processes. The new biotechnology presents a suite of new possibilities, ranging from interspecific genetic transfers via genetic engineering to new tissue-culture techniques for mass-producing specific plant varieties (U.S. Congress Office of Technology Assessment 1991), all of which contribute to new ways of confronting and taking hold of plant biology for commercial purposes. There is every reason to suspect that biotechnology will have a significant commercial impact on tree improvement (Strauss, DiFazio, and Meilan 2001), including its social organization (see, e.g., Sagoff 1991). This potential is suggested not least by the sweeping political economic restructuring of public and private science that has gone hand in hand with the advent of biotechnology more generally (see, e.g., Slaughter and Leslie 1997; Kevles 1998; Kay 1998, 2000), and, more specifically, by the role of biotechnology in opening "new economic spaces" (Kenney 1998)[10] via plant commodification in industrial agriculture, particularly in the United States (see, e.g., Busch 1991; Krimsky and Wrubel 1996; Boyd forthcoming).

As yet, this potential and the tensions it portends for co-operative and publicly supported tree improvement are barely evident. For instance, there are currently no genetically engineered forest trees in commercial plantations in the United States Reflecting the ongoing significance of specific biological properties in shaping and constraining the appropriation of forest-tree reproduction, work with at least some forest trees has been slowed by the fact that their genomes are relatively complex and take longer to map, and also by difficulties propagating some species from shoots or tissue. Thus, while the first successful regeneration of a transgenic tree (a poplar) occurred in 1987, the first successful experimental regeneration of a *non*transgenic conifer—specifically, Norway spruce (*Picea abies*)—took place only in 1985, while the first successful regeneration of a transgenic conifer (a spruce) was accomplished in 1993 (Séguin, Lapointe, and Charest 1998). Work with Douglas fir has exhibited both problems, since the species has a relatively complex genome and is also difficult to propagate vegetatively. Thus, according to a forest geneticist, "Producing a transgenic plant with Douglas fir is technically very possible. Clonally propagating that [plant] and using it on a broad scale is much more expensive and technically challenging" (key informant interview, 3 September 1997, Corvallis, OR). In this respect, as in proprietary tree improvement, Weyerhaeuser stands out in its pursuit of somatic embryogenesis techniques to mass-produce genotypes of improved Douglas fir (Hee 1992).[11] More generally, however, work with species of poplar is more common, in part because natural growth rates in poplar are high and offer rapid returns to investment, in part because poplars have relatively more simple genomes, and in part because they tend to be very easy to clone (Donahue et al. 1994; Séguin, Lapointe, and Charest 1998; Strauss, DiFazio, and Meilan 2001).

The most direct evidence of the potential significance of biotechnology for Pacific Slope tree improvement is manifest in one of the more recent research co-operatives established in the region, the Tree Genetic Engineering Research Co-operative (TGERC), founded at Oregon State University in 1994. As the co-op's name might suggest, the explicit goals of its founders were to develop genetically engineered varieties of forest trees through co-operative research and, via this research, become the source of the first successful commercially deployed GE trees (TGERC 1999).

Reflecting the challenges of working with Douglas fir and the relative importance of poplars to work on forest-tree genetic engineering to date, TGERC research involves the production of GE varieties of hybrid black (*Populus trichocarpa*) and eastern (*P. deltoides*) cottonwood, hybrids now used in a relatively small cumulative acreage of pulp fiber plantations located primarily in eastern Oregon and Washington. The plantations are already among the most intensive forest-tree cultivation systems anywhere: trees are planted at a density of approximately 250 per hectare and harvested after six to eight years of growth at heights of 25 meters. Although actual rates of biological productivity for the plantations are carefully protected firm secrets, even a rough guess based on these figures indicates rates far in excess of those on conifer plantations further to the west. Moreover, reflecting the ease with which they are propagated from shoots, each block of trees in a plantation is planted with a single clonal variety selected for its advantageous growth properties (key informant interview, 8 August 1997, Wallula, WA).

At the TGERC, researchers have successfully developed prototypes of GE cottonwoods, which are in field trials in Oregon under regulatory review by the Animal and Plant Health Inspection Service of the U.S. Department of Agriculture as well as by the Environmental Protection Agency (Strauss, Knowe, and Jenkins 1997; Strauss, DiFazio, and Meilan 2001). To date, TGERC research has pursued three principal avenues: engineered sexual sterility, insect resistance, and herbicide resistance (key informant interview, 3 September 1997, Corvallis, OR). While engineering the latter two traits is of direct commercial interest, attempts to engineer reproductive sterility in the trees is considered a precursor to commercial deployment of any GE varieties of the cottonwoods in order to control the spread of introduced gene constructs to wild populations of cottonwoods (Strauss, Rottmann, and Sheppard 1995; Brunner et al. 1998), a key regulatory and public policy concern.

The TGERC research on engineered insect resistance makes use of an increasingly common technique in GE food crops involving the production of *Bacillus thuringiensis* toxicity by means of the insertion of a gene extracted from a common soil bacterium from which the toxin derives its name (TGERC 1997; Strauss, DiFazio, and Meilan 2001). The result is a plant that produces Bt toxin—a common agricultural pesticide—in its own tissues. Bt toxin is widely used to control cottonwood leaf beetles in conventional cottonwood plantations. Thus, the chief commercial advantage of Bt cottonwoods is that they promise to eliminate aerial spraying, something that could have economic and ecological benefits if it reduces the total amount of pesticide required (Strauss, Howe, and Goldfarb 1991) and the dispersion of pesticide into the surrounding environment (Krimsky and Wrubel 1996; James et al. 1998; Strauss, DiFazio, and Meilan 2001). Another commercially significant feature of the TGERC Bt-cottonwoods is that they contain a proprietary gene construct (owned by either Mycogen or Monsanto), opening potential revenue streams for these firms from commercially cultivated, proprietary (i.e. commodified) varieties.

A similar "advantage" is also a feature of glyphosate-resistant or "Roundup-ready" cottonwoods (Strauss, Knowe, and Jenkins 1997), the third major research emphasis at the TGERC. Prototypes of such cottonwoods are also in TGERC field trials. They would be of interest in existing plantations because glyphosate is toxic to conventionally bred hybrid cottonwoods and is now of limited use in the plantations (Strauss, DiFazio, and Meilan 2001). As their name suggests, these trees are also tied directly to Monsanto, the producer of Roundup, a common glyphosate-based herbicide, and the owner of the gene construct(s) used in this research.

In many ways, the TGERC builds on and extends the co-operative tradition of tree-improvement research and development in the Pacific Slope region. Based at OSU in Corvallis, the TGERC is a joint undertaking relying on state and private-sector inputs and contributions of research staff and facilities from the university. Members originally included major owners and operators of cottonwood plantations in the region and interested public agencies, including the Department of Energy and OSU (key informant interview, 3 September 1997, Corvallis, OR). Subsequent additions included forest-products giants International Paper, Georgia-Pacific, Weyerhaeuser, and Westvaco, which, though without significant investments in cottonwood operations in the region, expressed interest in potential applications of the co-op's research in GE forestry. In 1999, the TGERC embarked on its second five-year research plan; at that time, it claimed as members Aracruz Cellulose, Alberta Pacific, the Department of Energy, International Paper, the National Science Foundation, OSU, Potlatch, Westvaco, and Weyerhaeuser (TGERC 1999).

In other ways, however, the TGERC is clearly set apart. Monsanto and Mycogen have also been involved as associate members, for reasons that are not difficult to discern. The co-op has formal license agreements covering gene constructs owned wholly by these firms. The companies thus have a direct financial stake in potential licensing fees from commercial deployment of GE trees containing the genes they own. Moreover, under the auspices of the OSU Office of Technology Management, formal patent claims have been filed with the U.S. Patent Office under the ownership of the TGERC and OSU for a range of products and processes, including transgenic trees produced by the co-op. This is a first for tree improvement in the region.

It is far too soon to tell to what extent the advent of genetic engineering may lead to a more proprietary form of tree improvement and an increasing role for "private science" in forestry more generally, as has been forecast by some observers (see, e.g., Sagoff 1991). However, the TGERC experience already demonstrates the extent to which genetic engineering in tree improvement is being accompanied by the creation of more formal and exclusive property rights, including more strictly controlled forms of technology transfer from public to private science as well as among private firms. This tendency toward formalism may signify the emergence of a more complete commodification of improved forest trees, involving some combination of more exclusive, bilateral partnerships between academic science and capital and more entirely exclusive endeavors by individual or multiple firms in the production of proprietary forest-tree varieties. Examples of the former are a hallmark of agricultural and health biotechnology research, including, for example, a highly controversial exclusive partnership between the University of California-Berkeley and Novartis covering agbiotech, signed in 1998.[12] The latter has already occurred in forestry, exemplified by the formation in January 2000 of ArborGen, a wholly private joint venture by industry giants Westvaco, International Paper, and Fletcher Challenge together with a New Zealand genomics company by the name of Genesis Research and Development (Brown 2001). According to its partners, ArborGen's goal is to be the first to commercialize GE trees.

Conclusion

The TGERC does extend both the co-operative, publicly supported model of Pacific Slope tree improvement and, more generally, longstanding tendencies in the political economy of forestry research in the United States. On one hand, tree improvement—including the TGERC's incursion into GE trees—is an important facet of the protracted transition from timber extraction to plantation cultivation, one aspect of the increasingly social production of nature in the forest sector. On the other hand, the specifically co-operative and publicly supported character of Pacific Slope tree improvement, including research, indicates a particular strategy by which this social production has been undertaken in response to the specific biological challenges and uncertainties involved. This includes the "problem" of biological time, manifest as slow growth and sexual maturation rates, the challenges of controlling gene flow in open pollination regimes, the biological barriers to mass propagation techniques, and the combined geographic effects of provenance and fragmented property ownerships, all of which have, to date, made private and more exclusive and proprietary investment in the improvement of the Douglas fir a dubious proposition for regional capital. This comprises an historically informed regional case study demonstrating ways in which the formal subsumption of biophysical nature (Boyd, Prudham, and Schurman 2001) also entails the inscription of biophysical characteristics and dynamics onto the institutional organization of nature's social production (Smith 1984; Leff 1995), a form of ecoregulation (Benton 1989).

Yet the inscription of nature into political economies of capitalist nature and scientific research is clearly not a static portrait of institutionally efficient or equilibrium strategies, if this case is any indication. That is, cooperation between specific capitalist firms, aided by both public and private science, comprises a particular strategy in response to specific challenges in time and place. As these challenges are confronted and transformed—in part but not exclusively via the application of the new biotechnologies to forest tree cultivation—it is reasonable to expect that the political economy of nature's social production in Pacific Slope tree improvement will also change. The best evidence for this may be the ways in which biotechnology has reconfigured health and agricultural research in the United States, as well as the specific commodification of plant reproduction in American agriculture. And, as I have argued, while the TGERC has to date been co-operative and heavily assisted by state science, the increasingly formal management of trees and tree genetic resources as property under its auspices is suggestive of the more complete commodification of forest trees and an eventual "vertically integrated silviculture" (Sagoff 1991) that biotech and specifically GE trees may bring about.

However, two challenges confront these tendencies. One concern is that there are genuine ecological risks associated with commercial deployment of genetically engineered trees. These risks are potentially significant, not least as they become obstacles to regulatory and broader social sanction and thus to the viability of commodified nature. These concerns underscore, for example, the contingency of regulatory evaluation of TGERC GE trees now under way. There seem to be good reasons to worry that introduced genes will spread to wild populations of poplar, and possibly to other species of plants (Radosevich, Ghersa, and Comstock 1992; Duchesne 1993; Strauss, Knowe, and Jenkins 1997). In fact, despite a generally lower level of public controversy, GE trees likely entail a greater risk of engineered genes spreading into nontarget populations than do engineered agricultural crops, an issue that has sparked a growing scientific and public debate (Strauss, DiFazio, and Meilan 2001). This is because industrially cultivated trees are more closely related to noncultivated, or "wild," trees than are most crops, given the short history of forest-tree cultivation and the primarily "wild" genetic resources used in tree improvement (Freidman and Foster 1997).

The second problem is more social in character and involves, in particular, the potential for social opposition to GE trees, whether related to environmental concerns or to those pertaining to the potential political-economic implications of biotechnology in forestry. In March 2001, members of a group identifying itself only as "concerned OSU students and alumni" destroyed approximately 1,200 genetically engineered TGERC prototypes and other hybrid cottonwoods at testing sites near Corvallis and outside Klamath Falls, Oregon. In a subsequent press release, the group declared its opposition to genetic engineering of forest tress at OSU, stating "The test plots of *Populus* genus trees (poplars and cottonwoods) at these places were independently assessed and found to be a dangerous experiment of unknown genetic consequences" (letter to Dr. Steve Strauss, OSU forestry professor and leader of the TGERC, from a group identified only as "concerned OSU students and alumni," 23 March 2001; quoted in Genetix Alert News Release 2001). Other incidents in recent years involving protests against genetic engineering in forestry point to the fact that public acceptance of GE trees is by no means assured.[13] The actual probability that engineered gene constructs will escape to nontarget populations and the broader biological implications of tree improvement for genetic diversity, when combined with the politicization of these issues, bear all the hallmarks of ecological crisis tendencies as defined by O'Connor (1998): part objective, material transformation of nature, yet inescapably politically interpreted, defined, and constructed.

At the same time, it is equally possible that commercial development of forestry biotechnology from publicly supported research, including GE trees, will bring greater scrutiny and organized social opposition to state support for such projects than has hitherto been directed at the applied and research tree-improvement co-operatives. With relatively little fanfare, the silvicultural research co-operatives critical to various aspects of industrial forestry in the United States have blurred the distinction between public and private science, conferring, as they do, exclusive access to research results as well as significant control of research governance on private, capitalist firms. This troubling trend is consistent with a much broader shift in academic-industrial relations in biological research in the United States since at least the early 1970s (see, e.g., Wright 1994; Slaughter and Leslie 1997; Creager 1998). The salient issue is surely neither the role of private money in public and academic research per se nor the commodification of academic and/or state-supported research, although some do argue these points. Rather, it is the degree to which private money comes in the form of exclusive alliances, thereby privileging certain private-sector actors in the conduct of the research itself (not least via corporate governance over research funding), while at the same time radically intervening in peer review and academic publishing as traditional avenues for the dissemination of research findings in academia.

These kinds of concerns are, in fact, central to my own motivation in undertaking this research and writing this article. By interrogating the institutional foundations of Pacific Slope tree improvement, I intend both to explore important historical antecedents of contemporary scientific and industrial forestry—including the development of forestry biotechnology—and to understand the particular political economic avenues by which new natures are being produced. The "reinventions of nature" that biotechnology entails comprise simultaneously technical, scientific, and sociopolitical projects (Harvey 1996; Haraway 1997) with specific histories and geographies. In short, far from being inevitable, they are contingent. Any critique needs to embrace all of these aspects of nature's social production, lest the products of these efforts—the new natures—be reified as mere "things" and not understood as processes and social relations (Levidow 1998). Specific objections to genetically engineered trees, whether based on assessments of ecological risk, the ethics of manipulating and controlling life itself, or concerns about proprietary control of life forms, must consider the specific social origins of these projects, including, in this case, almost one hundred years of science and capital working together in tree improvement. Engaging such histories is integral to a reimagined politics of the production of nature.

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Notes

1. Pomeroy used this as the title for his seminal regional historical portrait (1991), although he intended to include the region west of the Rocky Mountains, including Idaho, Utah, and Nevada. I am primarily concerned with the region west of the Cascade Range, often referred to as the "Douglas fir" region (see, e.g., Mead 1966). Nevertheless, I use the term "Pacific Slope" here in order to capture broader regional tendencies than are suggested by the species-specific connotation of the Douglas-fir region label. Note, however, that Canada is excluded from both Pomeroy's use and my own. In both cases, this is largely because of distinct institutional differences that run through the histories of the U.S. and Canadian Pacific regions, but this exclusion should by no means be considered beyond question. For a different notion of the historical geography of both the West Coast forest sector and scientific forestry in western North America, see, for example, Rajala (1998).
2. In December 1899, Frederick Weyerhaeuser of the Weyerhaeuser Timber Company of Minnesota negotiated the purchase of 360,000 hectares of Washington and Oregon timberlands from the Northern Pacific Railroad, headed by Weyerhaeuser's St. Paul, MN neighbor, James J. Hill. The price was U.S.$5.4 million, or about $15 per hectare. Weyerhaeuser then bought a further 152,000 hectares in Oregon and Washington in August 1901, some at $15 per hectare and some at $12.50 hectare (Twining 1994).
3. Munger went on to become the first director of the U.S. Forest Service's Pacific Northwest Forest Experiment Station in Portland, Oregon, beginning in 1924.
4. Tree improvement is the systematic breeding of forest trees for the purposes of enhancing commercially valuable traits (Daniels 1984). It bears emphasizing that notions of "superiority" and "improvement" in relation to genotypes are a commercial construction in tree improvement. That is, tree improvement refers entirely to traits perceived to be advantageous from a commodity-production standpoint, including, for instance, height and girth, but also straightness of trunk, branch density, branch angle, and others.
5. I also had the opportunity in the fall of 1997 to sit in on the annual meeting of one of the region's most important silvicultural co-operatives. This led to several interviews of attendees and to invaluable insights into the inner workings of the institution, not least its decision-making dynamics.
6. Elmar Altvater (1993) also constructs a specifically ecological notion of capitalism's contradictory tendencies, based in part on the implications of the second law of thermodynamics for the circulation of value.
7. The same may be said of research on the genetic determination of drought resistance (Ferrell and Woodward 1966).
8. The problems "stem" largely from the fact that flowering trees may be fifty to sixty feet tall, making it difficult to reach the flowers. Trees tend also to be widely spaced, meaning that each tree must be accessed individually. Once the flowers are reached, collecting the pollen is a challenge, particularly using mechanized methods. And, since it is difficult to identify the exact time when trees are in flower, spraying pollen on a receptor tree to manipulate crosses produces relatively low success rates.
9. Silen went on to work with the Forest Genetics Team of the U.S. Forest Service's Pacific Northwest Research Station, located on the campus of Oregon State University.
10. This term is Schumpeter's (1939); Martin Kenney (1998) uses it specifically to refer to the creation of new paths of capital accumulation via the commodification of biological processes enabled by biotechnology.
11. Along with Westvaco, Weyerhaeuser is a leading firm in research on somatic embryogenesis in conifers. Together, these firms accounted for thirteen of the twenty-one patents for somatic embryogenesis issued between 1989 and March 1998 (U.S. Patent Office, Patent and Trademark Center 1998). Weyerhaeuser also holds a total of nine patents related to the production of manufactured seed, a related technology for encasing the cultured embryos.
12. In November 1998, Swiss pharmaceutical, agrochemical, and biotechnology company Novartis signed an agreement with the Department of Plant and Microbial Biology at the University of California-Berkeley. The deal provided the department with $25 million in funding from Novartis and access to the company's gene-sequencing and DNA resources. In return, Novartis received right of first refusal over licensing patent rights from all research conducted using the funds, and also gained two seats on a five-member departmental panel established to allocate funds to research projects. The deal was and remains highly controversial at Berkeley and in wider circles because of the degree to which it

transfers to a single firm governance over research at one of America's leading publicly supported land-grant universities. This is part of a more widespread turn toward exclusive partnerships between universities (public and private) and private companies covering research funding *and* control over and dissemination of research results.

13. For example, in the United Kingdom in July 1999, protestors destroyed GE poplars being evaluated by AstraZeneca; in July 2000, activists destroyed what they described as GE trees planted by the Mead Corporation near Milo, Maine.

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