…Forest for the Trees
Biodiversity, Sustainability and Risk
in the Transition to a Modern Forestry

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Over the past few decades, a huge number of new words have entered the global lexicon. Many are proper nouns (e.g. Internet, EU, GATT) and are thus almost universally identified. Others are more conceptual, rather than descriptive of present realities. Such terms, though widely used, are often difficult to define in practice. This has been true, even when they originate within the scientific community, or after they have been legitimized in official policy documents (Jasanoff 1998). Sustainability and biodiversity have been two of the most significant – as well as the most contentious. Each has a history of varied and contradictory usage, yet both are central to some of the most important policy dialogues of our time. Extensive literatures exist for each[1], though these have often suffered by being either too narrowly constrained by disciplinary boundaries, or too general to offer much substance. This essay draws on many such works, seeking to develop a synthesis that connects such theories to an empirical record that itself presents serious implications for public policy.

As a political issue, biodiversity has often been characterized as a conflict between alternative uses, or in terms of market failure (McNelly 1996). As a generalized good, biodiversity is promoted around the world, yet efforts to connect rhetoric to policy face criticism that they merely reflect or even reinforce global divisions of wealth or level of development. Obviously, determining the importance or value of biodiversity will always be colored by political and economic contexts. This is reinforced by the problem that the majority of natural biodiversity is not evenly distributed – diversity-rich forests and reefs are mostly located within the territories of the poorer developing nations, who may lack the administrative and fiscal resources to protect or husband them (Hyde et al. 1996). Financing biodiversity conservation is further problematized by political uncertainty as to which resources should be protected. Conservation efforts are often criticized for focusing only on "charismatic" species, or alternately, those so rare and "unappealing" that most persons have difficulty finding value in their preservation.

However, there remains a compelling reason for biodiversity conservation that has been largely missing from the mainstream dialogue. While much of the debate has focused on species seen as valuable in human terms (Willan 1995), this is most often framed in terms of *hedonic* (pleasure or well-being due to species protection) or *option* value (a species' possible future economic value). Yet a third choice remains – that *biodiversity is critical to the sustained function of the global food and fiber system*. In other words, biodiversity is vitally important to the basic elements of human survival, as well as the local and global economies founded on those processes.

This essay focuses on one sector of this system, the global forest products industry. It has been claimed that forestry has the potential to "become the first industrial system that can meet the need for food, raw materials and energy within sustainable systems" (Wergens 1995). For more than half a century, foresters have argued that forests had the potential to be renewed indefinitely, given wise management (Tidmarsh 1951). Though the term "sustainability" had not yet been coined, the concept undoubtedly existed – in fact, forestry science itself originated from such concerns (Sedjo et al. 1998). Yet despite such concerted effort, we know relatively little about dynamics influencing diversity in forest ecosystems, especially their relation to forest management (Hardner and Rice 1999). As a result, sustainable natural forest management has often been judged as less-than-successful (López 1999).

[1] For sustainability, see Daly 1994, Gane 1992, Holdgate 1993, Lélé 1988, Olson 1996, Rosenberg 1994, Smith 1993; for biodiversity, see Barker 1993, Baydack 1999, Cortner 1999, Glowka 1994, McNelly 1996, Tilman 1997, Vandermeer 1995 and Yachi 1999. Some, such as Boyce 1997, Freese 1997 and 1998, Maser 1994, Noss 1993, Poore 1995 and Sedjo 1998 attempt to integrate both concepts.

Many foresters now believe that an *agricultural* model has greater potential to consistently provide the world's need for wood products. They argue that transition to reliance on "planted forests" would relieve pressure on natural forests, even as they increase total wood production (Shapiro 1997) (Clapp 1995b). As the "logical outcome" of increased scarcity of natural forests for wood extraction, plantations are seen as the future of forestry (Pharis 1993) (Hyde et al. 1996). In 1996, it was estimated that plantations provided twice the amount of raw material for the world's pulp and paper industry than productive natural forests (FP 1996). The latter are expected to decline by almost 250 million hectares over the next three decades, while an increase in plantation area of only 27 million hectares is expected to take up the slack[2] (Mater 1999). Because the costs of establishing plantations has often been greater than extraction from natural forests, and because the lag between investment and returns stretches into decades, most were initially publicly planned and funded. Though the current trend is to encourage private sector investments, states still regularly subsidize planting efforts. While researchers have had difficulty determining whether these payments are genuinely needed to expand investment horizons, or are merely incidence of policy "capture," it is clear that many governments take an active interest in expanding their plantation forest estates (Clapp 1995a). This implies dramatic changes in the global forestry industry, as comparative advantage shifts from natural to planted forests (Abbott 1983).

The ecological changes implicit in this transition are also substantial. Although the effects of plantations on soil, water and air quality are highly controversial (Marchak 1995), the greater issue is the associated narrowing of genetic diversity. Though scientists acknowledge that many ecosystems possess a degree of "functional redundancy" (Noss 1993), forest plantations – currently characterized by a predominance of only one or two species – present a dramatic loss of biodiversity compared to natural forests (Sargent 1991). This presents a fundamental shift not only in our relationship to forests, but to the broader natural world (Bass and Sargent 1991). If plantation production is indeed the future of the forestry industry, it is imperative not only that we understand this transition, but that we also strive to make the next phase of wood production as sustainable as possible.

One of the greatest challenges facing an essay of this type is that there are so few essays of this type. In seeking to create a synthesis of disparate literatures, it is all too easy to align with only one perspective, reinterpreting all others in its terms. This need not be overly problematic, except that all too often such viewpoints follow traditional disciplinary boundaries that have already been found insufficient to fully address certain issues. Indeed, this is what creates the need for a synthetic view in the first place. The aim of this essay is to present such a perspective, relating the literatures of biology, ecology, economics and political science to an empirical record that concerns each. If successful, it will demonstrate not only a bridge between these fields, but will also present a compelling reason to cross that span.

Diversity and Sustainability

Natural science defines biodiversity along three dimensions: the genetic diversity within a species, the diversity of species within ecosystems, and as the uniqueness of ecosystems in regional or global contexts (Sargent 1991). Ecological stability[3], often a factor in sustainability of productive ecosystems, is principally related to the first two of these dimensions (Yachi and Loreau 1999). The first, long been considered important to agricultural systems, is associated with dependable yields and crop development (Panayotou and Ashton 1992) (Willan 1995).

[2] One hectare equals approximately 2.2 acres.

Genetic diversity is also considered critical to maintaining a species' long-term viability in the face of factors such as insects, disease and climate change (CAST 1999) (Dickson and Walker 1997).

However, recently researchers have begun to argue that genuine sustainability requires expanding concern for diversity to ecosystem levels (Dahlberg 1996). Non-susceptibility to disease and pest outbreaks is not merely genetic, but also ecological. Healthy, productive ecosystems can be maintained not simply by choosing resistant crops, but also by preventing the formation of conditions in which diseases and pests can thrive. While lack of genetic variation offers less disease resistance than more complex systems, the shallow ecological structures typical to plantations present fewer obstacles to pest species, also often the vectors of disease (Noss 1993) (CAST 1999). Diversity losses that lead to such conditions have been attributed to "major resource and economic bottlenecks," as crops are lost and obstacles to continued production arise (Ravi and Pushpangadan 1996). Considering the overwhelming importance food and fiber production at both local and global levels, it is critical that we strive to improve our understanding and use of biodiversity. In other words, the value of biodiversity is not restricted to hedonic or option value[4], but must be considered more broadly – as offering "enduring options for sustainable management" (Noss 1993).

Forestry

Natural forests are the world's most complex terrestrial ecosystems (Maser 1994). While concern about ensuring sustainable timber supplies has long been the subject of forestry research (Sedjo et al. 1998), conserving complexity has not always been considered crucial. For most of forestry science's history, *sustained yield* has been the principal goal – producing the maximum volume of wood in a given area, and sustaining that volume indefinitely (Lanley 1995) (Raga and Sierralta 1995). Only as biodiversity has gained currency in broader policy dialogues has it begun to be seen as important to the sustainability of the forest industry itself. Diversity in both tree species and forest composition is now seen to increase the capacity to respond to change – changes that are not always predictable, nor easily mitigated by technological sophistication (Hummel and Sizych 1997) (Sargent 1991). Maintaining or increasing biological diversity is gradually becoming considered an important forest management tool.

A Nascent Revolution

Despite concerns about preserving forests for non-timber uses and the development of sophisticated recycling methods and material substitutes, it is clear that the need for wood products will continue to increase for the foreseeable future. Prices will also rise (timber prices have been increasing for centuries) as the world's natural forest resources dwindle (Hyde et al. 1996) (Sedjo 198x). Evidence from a wide range of economic, social and ecological contexts show – as microeconomic theory would predict – that foresters react to scarcity of resources and growing prices by planting more trees (Hyde et al. 1996). This may at first seem trivial, but when considered against humanity's past relationships with forests, the significance of this

[3] There have been many critiques of the use of the terms "stability" and "health" to describe ecosystems. However, these arguments are most valid when applied to ecosystems that are relatively unimpacted by human activities. Since the focus of this essay is productive forest sustainability, it is reasonable to consider ability to survive environmental changes.

[4] Again, option value relates to potential gains of the exploitation of a species at some point in the future. Although increasing stability may provide more options for sustainable management, it is problematic to describe this in terms of potential gain. More accurately, diversity provides a form of insurance against potential losses – perhaps its value is better described in terms of "resilience," "stability" or even "sustainability."

transition is striking. In the first decades of the 20th century, forestry began the final and potentially irreversible transition from "hunting and gathering" timber supplies to their conscious cultivation (Sedjo and Lyon 1983) (Abbott 1983). Forestry is shifting from total reliance on the productivity of wild species and natural cycles to selective breeding for desired characteristics and intensive cultivation of those species. In other words, modern forestry is undergoing a *neolithic revolution*, the same transition made by food production ten thousand years ago (Clapp 1995b). Forestry is becoming a form of agriculture.

In ecological terms, agriculture is characterized by the centrality of domesticated plants – commonly called crops – within a productive system (Harris 1996). A plant is considered domesticated when genetic selection has made it both physical distinct from relatives reproducing in the wild, and at least partially dependent on humans to complete its lifecycle (Simmonds 1985). Yet the adoption of agricultural processes by forestry has a far greater potential impact – by definition, agriculture is to some degree *artificial*, involving dramatic changes in diversity and ecosystem function (Harris 19xx). The productive capacity of agriculture is made possible by converting landscapes to less complex *pioneer* states, in which aggressive, short-lived plants thrive. Such ecosystems are capable of more rapid production of biomass (plant or animal life) than those with more complex structures, but are also inherently more unstable, requiring continuous monitoring and control (Sargent 1991). In other words, agriculture changes low-input, relatively stable and complex ecosystems into high-input, unstable, and greatly simplified systems, dedicated to the production of a narrow range of species – a textbook definition of plantation forestry (James 1989). Although the harvest of wood products from natural forests is likely to continue well beyond the foreseeable future, the evidence is overwhelming that forestry has begun the transition to a full-fledged agricultural system.

Plantation Forestry

Although forest plantations have existed for centuries in Europe, they were rare in the rest of the world prior to 1940 (Sedjo 198x) (Sargent 1991), in part due to the delay on returns to investment, typically greater than an individual's lifetime[5] (Clapp 1995a). Since then, they have become the main sources for the world pulp and paper industry, supplying twice the raw material of natural forests, a trend that is likely to deepen in the decades to come (FP 1996). While current expansion is principally funded by private forestry interests, most plantations began as public sector projects, due to the size of the initial investments and lengthy delay on returns. Today, large-scale planting is still often supported by subsidies and directed government programs (Clapp 1995a). The continuation of this process is likely to transform the international forestry industry, as comparative advantage becomes a function of investment in fast-growing species, rather than wild resources (Abbott 1983). These new species grow so rapidly that the lag time between harvests has been reduced to mere decades (Clapp 1995a). As a result, the plantation model has also been embraced by the mainstream of the development community. During the 1990 Uruguay Round, World Bank officials suggested ending extraction from natural forests, arguing that plantations were the "only truly sustainable alternative" (Pharis 1993).

Forestry plantations are intensively managed agricultural systems, based on the controlled breeding and cultivation of a restricted range of trees that have been carefully selected for characteristics such as total yield, form, and wood properties (ibid.). Though many forests

[5] Hence, requiring what has been called "landesque" capital, with investment horizons that stretched into centuries (Clapp 1995a). Admittedly, this is difficult to envision in a contemporary economic context.

considered to be "natural" are also often intensively managed, plantations are distinct by their degree of structural and genetic simplification – even to the point of *monoculture* (single-species ecosystems) (Sargent 1991). This narrowing of diversity greatly simplifies their management, increasing predictability and the uniformity and volume of materials, and often generates economies of scale unavailable to natural forestry (Krebs 1976) (Panayotou and Ashton 1992) (Clapp 1995b). Their primary function is to produce low-density softwood trees for sawn timber, wood chips and paper pulp (Marchak 1995), which they produce in far greater volumes (over time) than natural forests (Sedjo and Lyon 1983). Forest managers have argued that although plantations have sometimes displaced natural forests, they are in fact complementary to them. They claim the increased productive capacity will enable increased protections of natural forests, even as both supply and demand of wood products continues to increase (Sargent 1991) (Dourojeanni 1999).

While some foresters may see the goal of commercial forestry as maximizing wood fiber production, there are other economic considerations as well. Conventional cost control models show that plantations are most efficient when they concentrate on only one or two species – other considerations merely divert resources (Maser 1994). Yet an economic argument can also be made for maintaining a greater flexibility of production; demand for any particular wood product may change more rapidly than investment can yield returns; in the face of such economic uncertainty, it seems prudent to maintain the ability to produce a range of species (Krebs 1976).

However, monocultural production poses even greater biological and ecological risks. Large-scale disease outbreaks are not uncommon in other monocultural agricultural crops, such as wheat and rice (Pharis 1993). The much longer lifespans of tree species greatly increases the odds of such diseases being introduced or evolving within forest ecosystems. This risk is heightened by the very narrow genetic base of forest plantations. Forest ecosystems commonly limit the spread of disease (as well as insect pests) through greater biological diversity, both within and between species[6]. Foresters acknowledge that it is much more difficult to control disease in monocultural forests, and that this often causes greater damage than would occur in a diverse system (James 1989). This potential is well-known within the profession (Panayotou and Ashton 1992), though few plantations have actually been completely destroyed (Bass and Sargent 1991).

In the early 1970s, a New Zealand novel, <u>The Death of Grass</u>, depicted a disaster in which fast-striking disease devastated nearly every grass species – virtually all of the world's grains[7] (Sutton 1998). Should such a disease strike a major plantation forestry species, civilization would be profoundly changed. While this may seem far-fetched, it is important to realize that similar diseases have already decimated several species (e.g., Dutch elm disease, chestnut blight and white pine blister rust) (Barnum 1996). Worldwide, disease is the number one cause of reduced tree growth, and thus biological and economic productivity. Approximately 50,000 diseases are known to attack tree species (Sharpe et al. 1986). Should a fast-acting, destructive disease spread through the world's plantation forests, we could be facing the equivalent of a "modern-day potato famine" (Dahlberg 1996). Though some within the forestry industry insist that this is essentially an economic risk, borne exclusively by private investors (Raga and Sierralta 1995), the fact that tree planting only appears economically feasible when publicly financed belies the point.

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[6] Although essentially single-species natural forests exist, they are unusual (Krebs 1976).

[7] *Dennis – unfortunately, I have been unable to locate the full citation (still trying, though).*

Monterey Pine (*P. radiata*)

Worldwide, fast-growing softwood pines are a staple of the forest industry. Considered the "bread and butter crop" of plantation forestry (ES 1996), pines exactly match the needs of plantation management – they are pioneer species, they reproduce easily and grow rapidly, and there is a steady demand for their wood fiber (Clapp 1995b). *Pinus radiata*, also known as *Monterey pine* or *insignis*[8], is the undisputed king of plantation pines. There are no other tree species with the characteristics that make radiata pine so successful (Krebs 1976). While wild radiata can live up to 150 years, the tree reaches its maximum annual growth at 18-24 years; this exceptionally rapid growth means much faster return on plantation investments (Clapp 1995a). In the past hundred years, it has grown in importance from an ornamental species to the most widely planted tree in the world (Clapp 1995b). In the process, intensive selection and breeding programs have created a "well-characterized" domesticated variety, with consistent form and growth (Kanowski 1997). For decades, radiata plantations have produced raw material for sawn timber, wood chips and paper pulp (Sutton 1997). It has also recently been discovered that its bark is a highly concentrated source of antioxidants, used to combat arterial disease and cancer (McNelly 1996).

Radiata pine is the heart of the softwood industries of Chile and New Zealand, and is economically important to Australia, South Africa's Cape Province, Spain and Portugal (Clapp 1995b) (Dickson and Walker 1997). Worldwide, radiata plantations earn more than US$4.5 billion each year (Barnum 1996). Producing more wood fiber per hectare, in less time than *any* other recorded species (Krebs 1976), radiata may be the most important single tree species in the world. William Libby, Professor Emeritus of Forest Genetics at UC Berkeley, has said that domesticated varieties of radiata pine have become as important as wheat, rice or corn (Kanowski 1997).

Though the largest stands of radiata are in Chile and New Zealand, the species was introduced to those countries only after the mid-19th century. Native to the central Californian coast, *P. radiata* is a "relict" species in its natural range – contrary to the success the species has achieved in the southern hemisphere, it survives in the wild in only three small stands (Clapp 1995b). This also means that radiata has one of the most restricted natural ranges of any tree species (Krebs 1976). These stands represent a critical resource for genetic improvement, including breeding and selection for growth, form and insect and disease resistance (Barnum 1996). Though even wild radiata has shown little genetic diversity, the situation is worse for producer countries, where huge areas are planted with cloned trees (Storer et al. 1995) (Clapp 1995b). While the species has naturalized[9] to some degree in each of the major producer countries, concern for the ecological integrity of indigenous forests has meant that radiata has not spread significantly in its adopted homes.

Chile

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[8] When radiata was first brought to the Southern Hemisphere in the last decades of the 19th century, the species was known as *Pinus insignis*. As a result, it is most commonly known as insignis in New Zealand and Australia, and as pino insigne in Chile (Krebs 1976).

[9] An introduced species is considered to have been naturalized when it has escaped cultivation and is able to complete its lifecycle in the new environs without human assistance. Outside of plantation boundaries, the species has been considered a "pest" in New Zealand and South Africa, because it is believed to compete with indigenous forest species. While the tree has also naturalized in areas of the Chilean countryside, concern there is less pronounced (Krebs 1976).

Chile has the world's largest holdings of radiata pine (Jélvez et al. 1990). Although today it is considered a major international producer of wood pulp (Meacham 1997), the country was not always so well positioned. Chile's current strength in forestry is based not on vast natural forest resources, but on a conscious effort by the country's leaders to create a significant plantation estate (Clapp 1995b). While it has been estimated that Chile was almost half forested at the onset of conquest, clearing and burning for agriculture reduced that area to only a quarter (Silva 1997b). In ecological terms, Chile is an island, isolated by the Andes mountains, the Pacific Ocean and the driest desert in the world, the Atacama. Because this has made natural plant and animal migration so challenging, the country has an extremely high incidence of endemic species[10] (Wilcox 1996). A half-century ago, those natural forests provided the sole resources for the national forestry industry. Today, nearly all of Chile's wood pulp is produced by plantations, 85 percent of which are radiata monocultures (Clapp 1995b). The species grows faster in Chile than anywhere else in the world, maturing in as little as eighteen years (Gwynne 1993). It has become the "backbone" of the Chilean forestry industry (Husch 1982), enabling the country to steadily increase forest product exports, even as it attempts to preserve its natural forests. As a result, nearly a fifth of Chile's territory is classified as protected, one the highest rates in the world (Meacham 1997).

Again, the current strength of Chile's forest industry has not occurred by accident or providence, but by the conscious effort of policymakers to create a resource for both domestic use and export (Clapp 1995a). The bulk of these plantations (more than 1.06 million hectares) have been established since the late 1960s, encouraged by targeted subsidy and tax policies (Marchak 1995). This project has converted much of south-central Chile from eroded wheat fields (as well as some of the indigenous beech forest) to an "industrial pine forest" (Clapp 1995b). The Chilean forestry industry currently estimates that radiata plantations cover 1.76 million hectares (CONAF 1999).

In 1997, these plantations produced more than 18 million m^3 of timber, nearly 80 percent of the country's forest products (TWP 1999b). In 1998, these exports earned US$1.6 billion, or more than 14 percent of all exports, despite the slump caused by the Asia crisis (CONAF 1999) (PM 1999). Forestry has been one of Chile's fastest growing export sectors for years (Nef 1995); in 1995 it was second only to copper (Wilcox 1996). Indeed, Chile is expected to become one of the ten largest forest products exporters this year (Jélvez, et al. 1990).

More than 80 percent of this productive capacity (and resulting wealth) is based on radiata pine. Because the tree grows so rapidly, it is often the only species that investors consider, creating vast monocultures throughout plantation regions (Wilcox 1996). While this may present the possibility of greater economic sustainability over indigenous forests, the degree to which plantations have concentrated on radiata has caused concern in Chile for almost as long as planting efforts have been underway (Krebs 1976). In 1997, over two hundred natural scientists issued a warning to the country's leaders that radiata plantations had come to threaten the integrity of Chile's natural environment, including biodiversity loss and degradation of soil and water resources (Canihuante 1997).

New Zealand

Although New Zealand was blessed with larger and more accessible natural forests than Chile, early colonists and Maori natives also reduced the forest cover to around a fourth of the national

[10] An endemic species is one not known to grow naturally anywhere else.

territory (Salmon 1993). Indeed, the first years of New Zealand's European history were said to have been "made of wood." By the late 1920s, with a "timber famine" eminent and widespread unemployment, the country's leaders initiated the first of a series of planting booms, relying almost exclusively on radiata pine (Wilson 1994). An early report, sketching the outline of such programs, claimed the effort would change the perception of forests as "mines to be gutted to that of a crop which could be perpetuated" (Roche 1990b). The idea seems to have stuck – in 1993, the forest industry signed an accord with environmental groups, agreeing to halt all cutting in natural forests, in return for their support in promoting plantations as a form of sustainable forestry (Sedjo et al. 1998). New Zealand's forestry industry is now based *exclusively* on plantation species, more than 90 percent of which is radiata pine (Horgan and Maplesden 1995). Though quite extensive, forestry plantations amount to less than five percent of New Zealand's total land area (Roche 1992). This is a remarkable confirmation of the claim that forestry plantations can reduce pressures on natural forests.

In 1998, New Zealand plantations produced 16 million m^3 of timber, generating US$2.2 billion export dollars (Atkinson 1998). Radiata pine accounted for 90 percent of this wealth, something only likely to increase in the future. It currently accounts for more than 95 percent of all new plantings (Horgan and Maplesden 1995). Such a concentration was not achieved without consideration of other species – to date, more than 400 different species have been tested in New Zealand nurseries. Radiata was chosen due to its rapid growth and the availability of seed stocks for large-scale planting, as well its apparent resistance to insects and disease (Roche 1990b) (Sutton 1997). Its phenomenal growth rate and amenability to intensive cultivation has meant it is the only species to interest major investors (ibid). Industry analysts project New Zealand's annual radiata harvests to reach 34.5 million m^3 within the next twenty years (FP 1996).

Challenges to Sustainability

Despite such unparalleled success, radiata pine is not without weaknesses. Some of the most significant have been suggested above – the importance of forest product exports, supported by monocultural plantations with exceptionally narrow genetic foundations, which in turn rely on a wild species with extremely limited natural range. It is not an exaggeration to say that there are some "scary things about radiata pine" (Willing 1999). Foresters are not blind to these risks; New Zealand analysts have argued that the introduction of a fast-moving, fast-acting pest or disease would be "devastating" to the country's forestry industry (Sutton 1998) (Clapp 1995b). Again, this is not mere fantasy – over 400 insects and diseases are known to attack the species (PM 1995). Radiata growers already face many of these; insects such as *Rhyacionia buoliana* (European pine shoot moth) and *Lymantria dispar* (Asian gypsy moth) have the potential to damage and destroy forest plantations (Clapp 1995b) (PM 1995) (Wilcox 1996). Fungi are another perennial threat, capable of striking at any stage of a tree's growth (Sharpe et al. 1986). *Dothistroma pini* (pine needle blight) and *Diplodia pinea* (tip blight) are common and can cause extensive damage to radiata, though foresters have found they can be limited by careful site planning, genetic resistance and chemical treatments (Husch 1982) (FBT 1999). *Dothistroma* is especially interesting, in that its spores can be carried hundreds of miles by wind alone (Sharpe et al. 1986).

Pine pitch canker – *Fusarium subglutinans*

In 1946, the fungus *Fusarium subglutinans* was discovered in a North Carolina forest (Storer et al. 1995). Commonly known as *pine pitch canker*, the disease acts by infecting branch tips and the root crown, the means by which trees grow taller and broader. The infection causes resinous cankers throughout the tree, which in turn offers an easy target for bark beetles (Dallara et al. 1995). By 1961, tests had shown that the fungus was pathogenic to radiata pine – once these trees are infected, they rapidly wilt and die (Storer et al. 1995). It was not until 1986 that fusarium was identified in the natural radiata forests of California (NZPA 1998b). The disease spreads so rapidly, and kills so quickly, that it is now estimated it could destroy as much as 85 percent of all wild radiata within the next ten years (TWP 1998a) (Walker 1998).

Since monitoring plots were established in 1992, researchers have discovered that the fusarium spore is spread principally by insects and birds, but that long distance transportation of infected plant materials is also a significant vector (Meier 1998). No other species is as vulnerable as radiata pine, though the disease has been shown to attack all commercially important California species, including Ponderosa and Douglas fir (NZPA 1998a) (Wood 1998). Researchers have called it the "most deadly disease in the entire pine tree family" (Walker 1998), with a destructive potential equal to Dutch elm disease, chestnut blight and white pine blister (Barnum 1996).

Unfortunately, foresters have been unable to find *any* effective chemical or biological control for the disease (Dallara et al. 1995) (NZPA 1998b). With no method available to cure or immunize trees, preventing the disease's spread has become critical to preserving radiata as an economic species (PPCTF 1996) (Owen 1997). Fusarium poses such a threat to California's forests that the state's forestry board established a "zone of infestation" in June of 1997, in hope of containing the disease. Although such controls are commonly used in California to limit the range of insect pests, this represented the first time a zone was declared for a disease (CFPC 1997). This may prove a difficult task – pine pitch canker has been found not only in the Southeastern United States and California, but now also in South Africa, Spain, Mexico, Japan and Haiti (CSIRO 1998). The United Nations recognized this risk in 1996, when it declared the species endangered (Barnum 1996). Last year, California environmentalists petitioned the U.S. Congress to have radiata listed as a threatened species (SDUT 1999).

Obviously, the threat is not limited to California. Both Chile and New Zealand have become very concerned about the potential for fusarium to spread to their plantations; forestry researchers from each have come to California to study the disease (Hanley 1998) (Atkinson 1998). The forestry industries of both countries have also become actively involved in research efforts to identify fusarium-resistant trees (CSIRO 1998) (TWP 1998a). Because any selection or breeding program to improve the tree's growth characteristics or resistance to disease need to be able to sample from a broad genetic base, significant losses of the wild stands could cripple those efforts (Dallara et al. 1995). Although geneticists estimate that up to 15 percent of the wild radiata may be resistant to the fungus (Barnum 1996), it has also been discovered that the seeds of infected trees can also be vectors for the disease (Storer et al. 1995). Based on this evidence, New Zealand banned all imports of pine seed in 1998, an understandable reaction to such a grave risk to the country's forestry industry (TWP 1998a). However, such policies will also further stifle the breeding programs; while it has been estimated that the minimum size of a viable breeding population is only 200 trees, they must be genetically distinct, not clones (Panayotou and Ashton 1992). Considering the extremely limited genetic variation in current plantations, the potential for improving radiata's disease resistance has now been severely handicapped.

The magnitude of this problem has only began to be realized. The absence of an effective treatment leaves radiata producers with no choice but to ask their governments to implement stronger restrictions on the transport of plant and animal materials suspected of being possible vectors for the disease. New Zealand's efforts to prevent the import of seed-borne fusarium shows how seriously governments consider this threat – the controls do not make allowances for testing of seed for spores, but simply prevent all potential vectors from entering (Hanley 1998). Foresters have said the introduction of a fast-acting disease would be "catastrophic" to the country's forest products industry (PM 1995). Because plantation stocks have been bred from such limited gene pools, and then often cloned from only a few genetically distinct trees, if fusarium were introduced, the damage could be much greater – more even than the 85 percent mortality rate in California's natural radiata forests (Barnum 1996).

Border control efforts can only be successful to the degree that the affected governments, industries, organizations and individuals coordinate to implement them (Owen 1997). Fortunately, the history of such cooperation is fairly long – the first international treaty on plant protection, signed in 1889, was also intended to contain a disease that attacked important cultivars. Since then, every agreement focused on plant species has had a similar aim – preventing the spread of disease and protecting agricultural stocks (Lanchbery 1998). Yet, while preventing the disease from ever being introduced to radiata plantations is obviously the best method of avoiding catastrophe, this approach has failed in the past – consider the impact of Dutch elm disease in both North America and New Zealand (CSIRO 1998). It is unrealistic to believe that *any* system of border checks can be absolutely effective in perpetuity.

Chile

Chile's biological isolation and distance from radiata's natural range has been of great benefit in limiting the introduction of pests and diseases known to attack the species. However, in a world of increasing cross-border transportation and transactions, this "natural" protection cannot last forever (Krebs 1976). The risks are greatly increased by selection and cloning from small, genetically narrow populations, and the practice of planting radiata in large, contiguous monocultures (Clapp 1995a). The importance of designing plantations that are more likely to resist pest and disease outbreaks is gradually becoming realized by Chilean foresters (Schlatter and Murúa 1992), though they have been criticized for years about the risks of creating a forest industry so overly reliant on one species (Laarman 1999). Even though the rotation period for radiata is shorter in Chile than anywhere else in the world, fusarium has been shown to strike even faster. The risk that fusarium or a similar disease could attack the country's plantations is heightened by their much narrower genetic base than the Californian stands. Until either a cure is found, or foresters are able to diversify or replant their plantations to resistant varieties of radiata, Chile's forest industry faces the risk of "catastrophic disease" (Clapp 1995a).

New Zealand

New Zealand has chosen to concentrate an even greater portion of its plantation estate in radiata, though they have known of the risks associated with monocultures for decades (Franklin 1957) (Pratt 1978). The appearance of fusarium and the dramatic damage it has caused the natural stands of radiata are beginning to seriously worry New Zealand foresters. While the country's plantations are now relatively free of serious pests and disease, introduction of a pathogen as deadly as fusarium could devastate the industry (NZPA 1998a) (Wood 1998). Forestry experts have warned New Zealanders that the country is dangerously dependent on radiata pine, comparing their situation to "a ferry carrying 200 people when it's meant to take 80" (Willing 1999).

This possibility is considered the single "greatest threat" to New Zealand forestry (Sutton 1998), despite the country's highly sophisticated forest protection infrastructure, considered one of the best in the southern hemisphere (PM 1995). Using rigorous searches of import cargo, quarantines and active research into breeding disease resistance, New Zealand has been able to limit the introduction and establishment of new pests and disease to an average of less than five per year (Sutton 1998) (PM 1995). Of course, this does not speak to the relative danger of the newly introduced species – the painted apple moth, the Asian gypsy moth and the tussock moth were shown to have broken through the country's strict quarantine more than two dozen times in 1998 (Kitchin 1999). Experts have said it is "only a matter of time" before fusarium breaches the quarantine and begins to spread (Barnum 1996). As in Chile, the current challenge is to discover a treatment for the disease, to replace existing trees with resistant strains, or to diversify plantations into other species.

The first of these goals has thus far proved illusory. The last two involve a race against time – whether foresters will be willing or able to replant their estates before fusarium arrives. Replanting with resistant varieties of radiata relies not only on the chance of identifying those varieties and reproducing them in quantities sufficient for the scale of these plantation systems, but also being able to introduce the new seed and seedlings without simultaneously bringing the fusarium spore. Moreover, selecting for resistance may adversely affect the other characteristics for which radiata is so highly valued, such as yield (Simmonds 1985). If this occurs, or should research prove unable to identify truly resistant strains of radiata, it may be wiser to begin replanting with a number of less-productive, but still economically valuable species (Libby 1997) (Willing 1999).

Even if the new trees (resistant radiata or other non-susceptible species) are capable of surviving with fusarium, foresters in both Chile and New Zealand will likely be faced with a trade-off between short-term yields and the longer-term stability of their industries. A harvest rotation period as brief as twenty years still presents a challenge; the unpredictability of environmental factors and the fallibility of even the most capable protection systems should more than encourage foresters to both retain and augment flexibility and resilience in their plantations (Sargent 1991). Decades of research into forest ecology supports the principal that diversity – at both species and ecosystem levels – increases the capacity to adjust to changing conditions (Hummel and Sizykh 1997). While there is undoubtedly some functional redundancy in natural forest structures, this cannot be said of monocultural plantations. Preventing the destructive potential of fusarium, or a similarly damaging pest or disease, is likely to require the inclusion of biodiversity as a central tool of forestry planning and management.

CONCLUSIONS

> "Where the future is uncertain, there is an overwhelming importance in biological diversity" (Sargent 1991).

One of the main purposes of this essay was to connect the theoretical perspectives on biodiversity from of a variety of fields to an empirical record that connects them all. A secondary goal, more relevant to the world of public policy and private investment, was to establish that concern for biodiversity is not merely a new form of conspicuous consumption, nor simply a means of guaranteeing future wealth for residents of the world's wealthiest nations, but rather that it is critical to sustaining food and fiber systems throughout the world. Whereas political scientists and economists generally speak of biodiversity protection as contributing to human wellbeing through such intangibles as hedonic and option value, improvements in our understanding of ecological dynamics show it to central to the sustainable productive use of plant and animal species. Despite the regularity of projections that science and technology will always be capable of solving the problems facing humankind and the complex systems upon which we rely, history has proven otherwise.

If plantations are indeed the future of forestry, we must begin to account for these limitations today. Ecological dynamics factor into even the most artificial of productive systems; for at least the foreseeable future, sustainable food and fiber production will depend on understanding and accepting these dynamics. This is a critically important point – although it has been said that sustainable systems must be economically competitive with conventional practices to be feasible (Keipi 1999), the reverse is also true – those practices must develop a long-term ecological stability equal to natural systems to be sustainable. While the relative size of human activity within the biosphere may have offered a degree of freedom from this rule in the past, the gradual disappearance of frontiers and "free" resources has permanently changed the rules. Modern forestry recognized this fact when it began the transition from gathering in the wild to cultivation. It is true that these "disappearances" are not always a direct function of excessive resource use; changing social values, given form through public policies that seek to protect natural forests, are also a significant factor. Yet despite the protestations of foresters still intent on "natural" timber production, these pressures have been tacitly accepted by those who argue that plantation production provides an alternative (Barnum 1996).

Considering the difficulties inherent in choosing between a "natural" forestry that nonetheless moves wild forests towards cultivation, and a plantation model that may prove untenable, biodiversity conservation obviously requires more complex institutional arrangements than simple fences, parks or wildlife preserves (Hyde et al. 1996). At the very least, sustainable production of wood products – a critical need for the foreseeable future – will require dramatic changes in current forest management practices, including plantations (Simberloff 1999). While the implicit message in statements that "plantations and natural forestry are complementary" is that the survival of the latter depends on a healthy and productive plantation industry, it is more likely that the sustainability of plantation production depends on maintaining healthy natural forests (Clapp 1995b). At the same time as forestry moves towards agricultural and industrial models, it must also strive to maintain its wild origins, even to the point of integrating them within the new techniques and systems of land use.

This truth is not merely ecological – economic conditions and market preferences are at least as volatile and unpredictable. Balancing diversity against productivity not only provides a hedge against pests and disease, but also enables foresters to more quickly respond to shifts in demand. One need only look at the various histories of developing nations to realize the importance of maintaining production flexibility. Diversified plantings can also allow producers to target more profitable niche markets, helping them to transition from pure commodity production (Horgan and Maplesden 1997).

Profitability is always placed in a delicate balance against risk, whether the risk in question is ecological, economic or political. As the forestry industry moves closer to completing its transition towards cultivation, investment in that sector also faces dramatic change. One of the most important lessons that forest planners must understand is that forests and plantations are not equivalents, though they may be complementary (Rivlin 1993). Their most significant difference lies in their relative genetic and ecological diversity. Natural forests are capable of supporting a broader range of goods and services, which can also limit their short-term productivity (Sargent 1991). Plantation forestry, by carefully channeling resources towards economically valuable species, may be more productive, but can also present a dangerous level of instability. Considering the large investments necessary to establish plantations, usually subsidized by public funds, such risks should be of broad concern. The fundamental question is whether private forestry should be allowed to externalize these risks, even as it increases them in the quest for short-term profitability. If public funds are necessary to establish (or re-establish) plantations, then the public sector has a role to play in ensuring that the risks assumed are not unreasonable.

Though fusarium appears to be a direct threat to only a dozen or so commercial species, other countries with significant plantation estates may do well to consider the warning it presents – economic dependence on the monocultural production of long-lived species is a substantial risk. Though future research may be able to stay a step ahead of the various biological challenges facing forest trees, there are simply no guarantees. Considering the magnitude of the investments already made in plantation forestry, their apparent inevitability as a component of productive forestry, and especially the substantial time lag between planning decisions and appreciable change, this faith seems overextended.

The temptation, when considering modern forestry as a new agricultural form, is to assume that similar dynamics of risk management apply. This is a dangerous illusion – differences between food and wood fiber production are great. Perhaps most significant is the dramatic difference in planning horizons. The former generally deal with annual rotations, whereas forestry systems measure harvest cycles in terms of decades. This longer period of exposure dramatically increases the vulnerability of these systems to unpredictable environmental risks such as pests and disease, as well as damage from wind and fire (Sargent 1991). Public influence in forest management processes may be necessary to persuade private industry to expand their planning and investment horizons appropriately.

This presents perhaps the greatest challenge of public policy – to act in the interests of broader society, including those generations not yet living. In essence, this question is the heart of the sustainability debate. Accepting that "nature is not only more complex than we understand, but that it is more complex than we *can* understand[11]" is a first step towards creating flexible and robust productive systems. Given that the state of our knowledge will always trail changes in the real world, it seems only prudent that we consider this factor when assessing risk and our capacity to overcome challenges. Modern forestry, as it switches from extraction to production, must take care to avoid the costs that attend misplaced faith in science and technology. Policymakers also need to be aware of these dynamics, and must be prepared to help the forest industry avoid dangerous hubris. Finally, it is important to understand that this is less a normative argument than a pragmatic, cautionary approach appropriate to the ecological dynamics that characterize all forests, be they wild or artificial.

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