Silviculture International Forestry

Even-Aged Silviculture in

Lessons Learned and Myths Perpetuated

In the past three decades tropical rainforests of the Far East have been managed using systems based almost exclusively on cutting cycles. Much recent research concerning this management approach has focused on reducing logging impacts on the residual forest. Evidence from historical records and research suggests that in certain circumstances shelterwood systems and their variants that provide both structural and age-class diversity can be appropriate. We give examples of such systems in India, Sri Lanka, and Malaysia.

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When foresters first contemplated the silviculture of complex moist tropical forests, their first impulse was to replace the chaos with pure plantations, a method they had learned from the reforestation of treeless European lands that had been degraded by centuries of grazing and farming. This approach has worked fairly well under favorable site conditions in the moist tropics, but only where natural forests had been virtually eliminated by human use or site preparation. The opportunity costs of such lands in Asia today seldom favor forestry.

In the 19th and early 20th century, tropical silviculture grew its first roots in South Asia and to a lesser extent in Francophone Central Africa and British West and East Africa. At the same time, North America was undergoing repeated waves of forest exploitation from east to west. In the 1850s the Indian Forest Service was founded under the direction of Sir Dietrich Brandis in response to overexploitation of high-quality timbers, particularly teak. In his classic work on initiating forestry in British India, Brandis described the potential direction for silvicultural research, including a focus on nontimber forest products, farm and village subsistence crops, and community forests, as well as the high-quality timbers (Brandis 1897).

Although forestry and silviculture research started in regions that were largely exploited for forest products by colonial governments, the establishment of a rudimentary local management and research infrastructure ensured some emphasis on the development of sustainable forestry practice. These institutions have lasted to this day in many South and Southeast Asian countries—along with all the administrative foibles of the time A wealth of gray literature from this research has since accumulated in journals, research records, internal reports, and unpublished manuscripts. Given the site specificity of much of this material, there are now large differences among regions and countries in the tropics regarding the ecological and silvicultural knowledge base for forest management. For example, most tropical forest regions in the Neotropics and Central Africa have little or no information compared to South Asia (India and Sri Lanka) and parts of Southeast Asia (Malaysia).

Much of this silvicultural knowledge has been documented in a form that is not widely accessible, borne out by the lack of acknowledgment this work receives from contemporary researchers on tropical forest management. Today foresters and researchers envision most Asian tropical forests as having balanced uneven-aged stands, and as being managed accordingly, almost to the exclusion of any other approach. Unfortunately, many of the mistakes made with uneven-aged silviculture in tropical Asia at the turn of the century (Wyatt-Smith 1963) have been forgotten, and as a result are being repeated. This paper attempts to clarify some of the more successful attempts at even-aged silviculture, and their variations with several age classes (double-cohort) in moist tropical forests of Asia, drawing on examples of historical work relevant to current issues in tropical forest management.

Selective Logging

The term "selective" was first coined to describe the partial cutting of west-

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A community forest managed under a single tree selection system *(tembawang)* in West Kalimantan, Indonesia. More than 100 species per hectare are managed in these "tree garden" systems. All trees shown are valuable timber or nontimber resources.

ern North American forests during their first periods of exploitation, and before markets for less valuable timbers had developed (Hawley 1935). The term is also used to describe the various policies of selectivity that extend over a whole range of concerns (or lack thereof) about long-term management of the stand. In the past 30 years, "selective" has been intentionally used in Southeast Asia to describe repeated diameter-limit cuttings at cyclical intervals, so-called polycyclic fellings (Whitmore 1990). Planned intervals between entries into the forest range from 15 to 30 years, based on the assumption that the removal of large canopy trees automatically releases existing seedlings and saplings of different sizes (and by implication different age classes) to form balanced, all-sized stands (Smith et al. 1997).

Since the 1980s these systems have been touted in tropical Asia as an ecological harvesting regime that, if properly done, can have a low impact on the remaining growing stock and can promote the forest structure (size-class distribution) and dynamic that many of these forests are perceived to have (Pinard et al. 1995; Pinard and Putz 1996; Primack et al. 1987a, b). These systems also have great political and commercial support on public lands: entries into a forest that are guided by a diameter-limit cutting to extract the largest trees generate large initial financial returns (Howard et al. 1996). In addition, high discount rates favor a reduction in the length of the felling cycle.

Nature's Bookkeeping

The less complex the stand mixture the easier it is to record mixture dynamics, as the simple mixtures of irregular uneven-aged systems (multiple-cohort) in parts of Germany and Japan attest (Smith et al. 1997). Though widely applied in the tropics, there are few examples of successful selection regeneration methods for moist tropical forests in Asia. Most documented examples have been indigenous "tree garden" systems that are highly labor intensive, so much so that tending is almost at the individual tree level. These systems represent almost complete analogs of natural self-thinning processes. But because human values drive tree species selection, these systems are usually employed in small stands that have been owned and passed down from individual to individual within communities or families, along with considerable knowledge of the system itself (for example, Padoch and Peters 1993; Peluso and Padoch 1996). The most successful uneven-aged selection systems documented in Asia are practiced by small holders who are more concerned with annual yields of nontimber forest products than with producing a reliable, long-term supply of sawlogs.

It is still too early to tell whether these systems can be practical and commercially viable on a large scale. It is unlikely that commercial enterprises will be able to generate enough profit from timber alone, so they must try to capture sufficient service value from recreation, carbon sequestration, or water to gain economic returns.

For larger commercial operations, the continuous monitoring and tending of uneven-aged stands can be problematic. This primarily relates to understanding the diameter distributions of the total stand, the individual populations that compose it, and the size-specific rates of growth of individual trees. The shape of diameter distributions of many rainforests in tropical Asia have been characterized as a reverse J (Whitmore 1990). Like many other regions (O'Hara 1998), researchers in Asian tropical forests have associated the reverse J size class distribution with all age classes being represented equally within a stand. However, this is not necessarily related to age-class distribution as is frequently assumed, with the small individuals being young and the larger ones old.

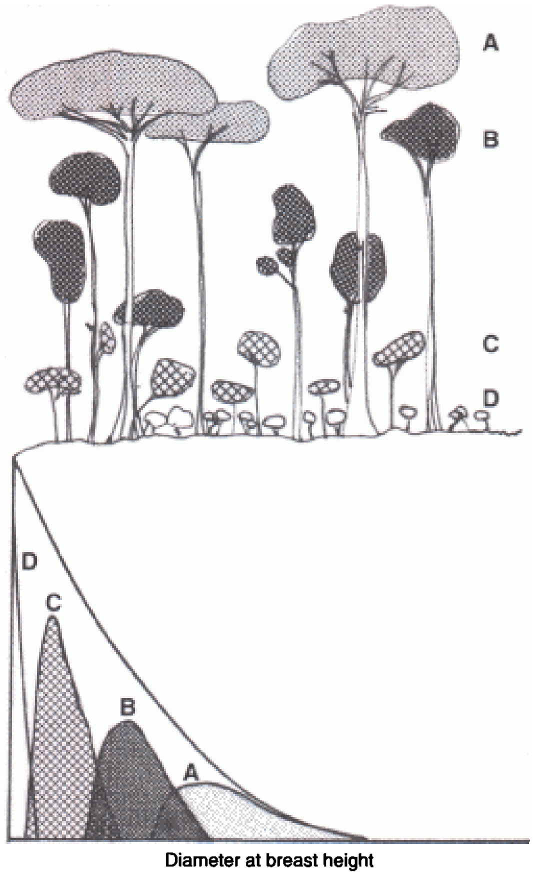

Figure 1. **Static stratification. *Top:* A profile of a mature (more than 100 years old) mixed dipterocarp stand, Sinharaja Forest, Sri Lanka. *Below:* A simplified diameter distribution for the species dominants corresponding to the profile. The profile comprises *Shorea megistophylla* (A—canopy and emergent tree), *Garcinia hermoni* (B—subcanopy tree), *Humboltia laurifolia* (C—a small tree of the understory), and *Agrostistachys hookeri* (D—groundstory shrub). The species listed correspond approximately in growth habit to northern red oak, sassafras, ironwood, and witch hazel, respectively.**

Species with different growth rates that occupy different strata within the forest (groundstory, understory, subcanopy, canopy, emergent) can all be the same age and still have a combined diameter distribution of a reverse J. This common phenomenon has been documented in mixed moist temperate stands that are even-aged (Oliver and Larson 1996; Smith et al. 1997).

Conceptually, two species stratification processes can contribute to the creation of a reverse J for even-aged stands. The first process includes those long-lived species that occupy different vertical strata within a mature forest stand. We refer to this as "static" stratification (even though the process actually is dynamic) *(fig. 1),* with understory species representing smaller and more numerous diameters than the true canopy and emergent species. Strong static stratification would be exhibited when tree mixtures with very different growth habits grow intimately together. A temperate example would be a mixture comprising witch hazel (understory shrub), ironwood

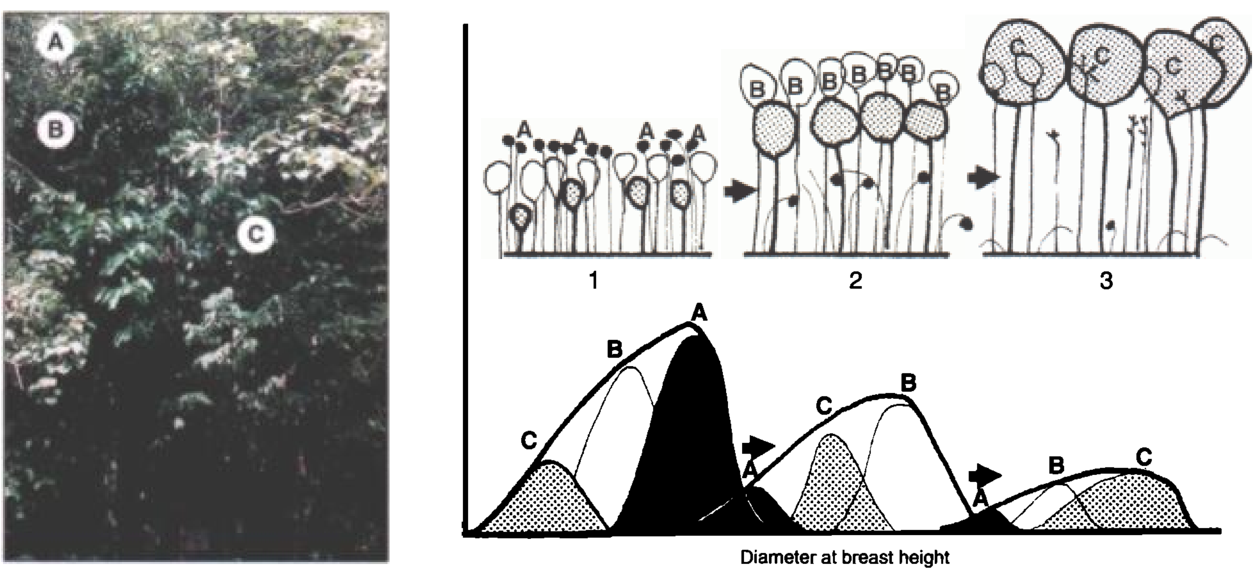

Figure 2. **Dynamic stratification. *Left:* A photographic profile of a 15-year-old mixed dipterocarp stand in stem exclusion phase, Sinharaja Forest, Sri Lanka. The photograph provides a snapshot of an early phase of stand development with the pioneer *Macaranga peltata* (A) in the canopy, mid-seral *Shorea trapezifolia* (B) in the subcanopy, and late-seral *Shorea megistophylla* (C) in the understory. The species listed are approximately equivalent in light tolerance to paper birch, northern red oak, and sugar maple, respectively. Species representative of truly below-canopy growth habits (those that comprise the different "static" strata in a mature stand) are also present in the understory depicted in this photograph. *Right:* A simplified depiction of the hypothetical change in diameter distributions for the tree species that attain the canopy at early, middle, and late phases of stand development (1—stem exclusion stage at 15 years; 2—stem exclusion stage at about 45 years; 3—understory initiation stage at about 80 years).**

(understory tree), sassafras (subcanopy tree), and oak (canopy tree).

The second process involves species of different developmental status (Swaine and Whitmore 1988) that sequentially gain dominance of the canopy with all species originating or being released together following an initial disturbance. A temperate example would be where pin cherry attains the canopy of the mixture early in stand development, but its position in the canopy is usurped first by black birch and then by red oak. We call this process "dynamic" stratification *(fig. 2)*. Both stratification processes occur together over the course of stand development following initiation, stem exclusion, understory reinitiation, and old-growth phases as described by Oliver and Larson (1996).

The majority of the canopy basal area in Asian tropical forests is represented by tree species that are relatively shade-intolerant and that produce periodic carpets of advance regeneration at the forest groundstory as a result of mast fruiting. The advance regeneration of some of these species may survive beneath a closed forest canopy for more than 15 years, but most survive no more than one or two years (Liew and Wong 1973; Ashton et al. 1995). In all cases the regeneration only satisfactorily establishes after release from a disturbance.

Shelterwoods for Regeneration

The shelterwood method of regeneration can be defined as a set of silvicultural manipulations applied at the scale of the stand and focused toward establishing advance regeneration when absent at the forest groundstory, and then releasing this regeneration as a single cohort once it is present.

The use of various kinds of shelterwoods as a silvicultural regeneration method in Asia has largely been ignored, mostly because of our concern for what we think forest structure should look like. Selectively taking the largest, most valuable trees—a desirable practice economically—is perceived as compatible with minimizing damage to the remaining forest structure. However, maintaining forest productivity and ensuring continued development over time is far more important to the issue of sustainable silviculture than is appearance. Expanding our appreciation of forest development from a single canopy gap to the level of a stand for financial and management purposes inevitably suggests the use of shelterwood regeneration methods. The development and use of such systems in South and Southeast Asia has a long history and provides a strong case for their future development and promotion.

As with any silvicultural system, there are constraints to the use of shelterwoods. This method can only be practiced successfully in stands with high merchantable volumes of valuable timber (> 40 m^3 per hectare) that have diversified markets, which enables silvicultural treatments to be done at a profit. Shelterwoods are most suitable for ensuring the establishment and then release of advance regeneration in forests that have canopy dominants that mast, and thus require substantial increases in light for regeneration growth. Examples of simple systems, where advance regeneration exists before final canopy removal, are the one-cut shelterwoods such as the Malay Uniform System for *Shorea leprosula* and *Dryobalanops aromatica* (Wyatt-Smith 1963); the system adopted for *Dipterocarpus zeylanicus* stands in lowland southwest Sri Lanka (Holmes 1957); and the overstory removal system adopted for moist sal forests *(S. robusta)* in Uttar Pradesh, India (Joshi 1980). These systems have been successful in large part because these forest types are dominated by one or two light-demanding timber species that regenerate prolifically. Such forest types are usually restricted to the flat lands and terraces along rivers, and to coastal lowlands of the Asian moist tropics. These lands are also the most susceptible to clearance for agriculture because their soils are fertile and easy to work.

The inadequate representation of advance regeneration in the more floristically complex uplands of tropical Asia led to development of more classical shelterwoods and their variants, and away from one-cut systems. Classical shelterwoods purposefully ensure establishment of advance regeneration before overstory removal through a variety of preparatory and establishment treatments to the forest stand. Both uniform and irregular shelterwood systems have been developed for the Andamans (Chengappa 1944), Western Ghats (Kadambi 1954), and currently in southwest Sri Lanka (Ashton et al. 1993). For Chengappa's system in the Andamans, the understory is gradually lifted in a series of preparatory and establishment cuttings that allow advance regeneration to first establish and then grow to pole sizes before canopy overstory removal. For the Western Ghat forests of Coorg, the partial removal of the overhead canopy and the complete removal of the understory is necessary to secure regeneration, after which the removal of the remaining canopy trees is necessary. In southwest Sri Lanka the degree of intensity of canopy removal changes with topographic position. Such systems cater to more varied ranges of species shade tolerance, and to the

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A one-cut shelterwood that released advanced regeneration of dipterocarp trees in lowland mixed dipterocarp forest at Sungei Menyala, Malaysia. The advanced regeneration was well established, allowing the overstory to be removed in one cutting operation. When this photograph was taken the released advanced regeneration had created a new even-aged stand that was now 30 years old and was in the stem exclusion stage (Oliver and Larson 1996).

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This photograph from a Sri Lankan Forest Reserve illustrates the nature of the ridge-valley topography of upland dipterocarp forests in South and Southeast Asia. In this instance the whole slope has been regenerated with an irregular shelterwood. The number of reserves retained in the overstory increases with stands that progress upslope from valley to ridge. This was done to accommodate the regeneration of more shade-tolerant dipterocarp species on the ridge as compared to those species in the valley. The valley stand can be considered an overstory removal; the midslope and ridge stands have approximately 25 percent and 50 percent, respectively, of the basal area remaining as reserves. The subcanopy of all the stands has been removed. The released regeneration is now 15 years old. The reserves in the two-cohort stands of the midslope and ridge are intended to be removed at the end of the next rotation.

changes in site productivity and species composition associated with the topographic complexity of upland hills.

Integrity Equals Income

By definition shelterwoods create a large-scale disturbance and simplify the age-class distribution and structure of a stand. Observations of shelterwood aesthetics after recent release only accentuate people's dislike for such systems. It is important to point out, however, that shelterwoods provide a more uniform crown canopy environment that facilitates self-thinning and moves the stand through the stem-exclusion phase (a critical period for species sorting) without residual damage caused by periodic intrusions from selective logging. Selective logging can promote significant environmental damage, particularly when economic justifications are made to reduce felling cycles and hence increase repeated incursions into the stand that disrupt stand development. Treated stands in shelterwood systems are therefore less susceptible to the opportunistic vine growth and chronic suppression of regeneration from ingrowth of older age classes, which provides enormous advantages in allowing canopy sorting of complex mixtures over a brief, albeit unsightly, period of early stand development.

Facilitating the release of specific age classes can permit the capture of other resources, such as nontimber forest products, that mature sequentially as part of the development of these stands. For example, in Sri Lanka we have been exploring the cultivation of cardamom *(Elletaria ensal)*, a fast growing herb whose fruit can be harvested for spice during the first five years after canopy removal; rattan *(Calamus thwaitesii)*, a climbing palm that ascends with the developing canopy in stem exclusion phase and can be harvested for furniture and basketry after 15 years; and kitul *(Caryota urens)*, a subcanopy palm of the forest that can be tapped for syrup after about 20 years. When combined, these nontimber forest products can double the income from a stand managed in a shelterwood system that is primarily managed for timber alone (Ashton et al. 1999).

Conclusion

In the right circumstances, even-aged silviculture can make biological and economic sense. All too often silviculturists and ecologists have slavishly imitated the scales of disturbance that nature uses, even though these may be logistically impossible to replicate given the kind of machinery and economies that we have today. A fresh perspective and better insights about stand dynamics in tropical forests often lead to more economical and biologically compatible silvicultural systems. This perspective will become increasingly important in future management scenarios when tropical forests are mostly restricted to uplands, with lands that are marginal for agriculture and plantation crops, where costs will be minimized, and multiple values of products (timber, fuel, nontimber forest products) and services (water, recreation) must be garnered from the same forest stand to make the whole forest economically viable.

Some of the environmental services (such as water) garnered from upland forests might appear to be incompatible with the use of shelterwood systems. This apparent contradiction deserves some clarification. We emphasize the importance of careful analysis in trade-offs between one-time severe incursions, followed by road and trail abandonment (roads are a major source of erosion), as compared to repeated but less severe incursions that rely on a permanent and expansive road and trail network.

Several lessons support management of tropical forest stands in even-aged mixtures. For example, the notion that different species can be treated as if they were of different age classes simply does not fit the way mixed stands develop because of interspecific differences in rates of height growth. Pretending that the low-value species in the subcanopy are young growing

stock may reduce costs, but it does not truly release advance regeneration. This phenomenon rings familiar to foresters in North America, where similar lessons were learned about species mixtures in the temperate mixed oak forests of the east (Oliver and Larson 1996; Smith et al. 1997; Miller and Kochenderfer 1998; O'Hara 1998).

The shelterwood principle of relying on advance regeneration ensures that the stand always has plants in place to ward off usurpation by explosions of invasive pioneer species that can exclude regeneration of timber species after they have been eliminated. In the end, it is easier and cheaper to ride along with the tendencies of natural stand dynamics in which the valuable canopy tree species continue to triumph.

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