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Large-scale, long-term silvicultural experiments in the United States: historical overview and contemporary examples

(With 6 Tables)

By R. S. SEYMOUR[1], J. GULDIN[2], D. MARSHALL[3] and B, PALIK[4]

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1. INTRODUCTION

This paper provides a synopsis *of* large-scale, long-term silviculture experiments in the United States. *Large-scale* in a silvicultural context means that experimental treatment units encompass entire stands (5-30 ha); long-term means that results are intended to be monitored over many cutting cycles or an entire rotation, typically for many decades. Such studies were installed widely between 1930 and 1955 when forest rehabilitation accomplished by partial cutting dominated research and practice, but fell from favor during the profound nationwide switch to even-aged silviculture during the 1960s (SEYMOUR, 2004). Concerns over the widespread use of clearcutting and the resulting even-aged regimes have rekindled an interest in the use of other silvicultural systems and large-scale and long-term experiments. Contemporary studies (since 1990) from four representative forest regions of the United States - the Northeast, Lake States, mid-South, and Pacific Northwest - are described and compared. Notable contributions of early (ca. 1925-1950) experiments, some *of* which remain active, are also reviewed, and contrasted to modern studies.

[1]) University of Maine, Orono, ME 04469, USA.
E-Mail: Ssymoyr@umenfa.maine.edtl
[2]) USFS Southern Research Station, Monticello, AR 71656, USA.
[3]) USFS Pacific Northwest Research Station, Olympia, WA 98512, USA.
[4]) USFS, North Central Research Station, Grand Rapids, MN 55744, USA.

2. HISTORY

2.1 *The Era of "Selective Cutting": 1925-1960*

Silvicultural research in the United States received a major stimulus in the late 1920s with the report from a National Academy of Sciences panel (BAILEY and SPOEFnt, 1929) and related passage of the McNary-McSweeney by Congress in 1928. By contrasting agricultural experimentation with silviculture experimentation, Bailey and Spoehr discounted the future of intensive production forestry that would later gain prominence during the 1960s, and instead, forecast that „... silviculture will be concerned, at least for an extended period, with the modification of relatively natural units of vegetation and with the restoration of more or less natural arborescent growth on devastated areas, rather than as in agriculture with extending the culture of a limited number of highly domesticated species under comparatively artificial conditions (p. 6)." They noted that the advance of forestry in Europe and Japan had been founded on „an efficiently systematized empiricism," and concluded that "... the extension of silvicultural management over the earth's vast area of wild forest land must be preceded by a comprehensive descriptive survey and analysis..., and by an intelligently formulated program of empirical experimentation..." (BAILEY and SPOEHR, 1929, p. 16).

In response to these developments,.the US Forest Service established experimental forests with large-scale trials of contrasting harvesting methods, nearly all of which were various forms of partial cutting using natural regeneration. Early examples set up prior to World War II, such as the Dukes Experimental Forest (ca. late 1920s) in the old-growth northern hardwoods of Michigan's Upper Peninsula (EYRE and ZILLGITT, 1953) and the Crossett Experimental Forest (ca. 1934) in the loblolly-shortleaf pine forests of the Gulf Coastal Plain (BAKER and BTsxoP, 1986) were typically unreplicated. A prominent objective of these early empirical studies was demonstrating what the researchers of the time considered to be "good forestry': typically light, frequent cuttings that built up and maintained high levels of growing stock (REYNOLDS, 1959; REYNOLDS, 1969). During the late 1940s, the Society of American Foresters' Division of Silviculture formed a "subcommittee on large-scale silvicultural tests" which compiled a detailed protocol for what had become known as "compartment studies" (OSTROM and HEIBERG, 1954). They recommended that treatments include various silvicultural systems of stand management and regeneration, product objectives or rotation length, intensity of cultural treatment, and volume of residual growing stock.

They focused exclusively on production and regeneration; noncommodity values were not mentioned. Also, the value of untreated controls, an essential feature in modern studies, was also not discussed, presumably because the "no-management" scenario was not viewed as a realistic option during this era. By the 1940s, some of Fisher's principles of experimental design were being addressed, and entire experimental forests were dedicated to replicated trials of alternative silvicultural systems. For example, the Penobscot Experimental Forest (ca. 1950) in the mixed northern conifer forests of east-central Maine contains two replicates of eight contrasting silvicultural systems (but no replicated controls), encompassing over 160 ha (SENDAK et al., 2003). Similarly, the Argonne Experimental Forest cutting methods study (ca. 1951) in second-growth northern hardwoods in Wisconsin contains three replicates of six treatments, including an untreated control (STRONG and ERDMANN, 1995). The Crrossett Experimental Forest installed a replicated study that compared growth and yield over time among two even-aged and two uneven-aged silvicultural systems, but without unmanaged controls (CAIN and SHELTON, 2001).

Although results often took two or more decades to develop, these early studies have made countless contributions to the management of natural forests in the United States. They provided the first reliable yield data for managed stands (e.g., EYRE and ZIr.r-GTTT, 1953; SOLOMON and FRANK, 1978; REYNOLDS, 1969; BAKER and MURPHY, 1982; GULDIN and BAKER, 1988); prior to ca. 1950; foresters were limited to normal yield tables that were applicable only to fully stocked, even-aged stands. Further observations on these studies after three or four decades provide further information on the sustainability of selection stand structures (e.g., FRANK and Bum, 1978; SEYMOUR and KErrEFIc, 1998; BAKER, 1986; BAKER et al., 1996; CAIN and SHELTON, 2001); indeed, the empirical northern hardwood structure derived by ARBOGAST (1957) from the EYRE and Zu.LGrrr (1953) studies has become virtually institutionalized in the Lake States and is widely used throughout the US range of *Acer saccharum* (SEYMOUR, 1995). Recent publications have documented the deleterious ecological effects of diameter-limit cutting, an exploitative harvest practice included in some early studies that remains common in mixed-species forests of eastern North America (KENEFIC et al., 2005).

2.2 The Era of Production Forestry: 1960-1990s

About 1960, many American foresters realized that "selective cutting" as generally practiced (with inattention to stand structure and regeneration) had not lived up to the potential of the selection system as envisioned by its early advocates (SEYMOUR, 2004). An abrupt paradigm shift to even-aged silviculture focusing on high-yield and low-cost wood production took effect in nearly every forest and ownership type in North America (BoYCE and OLIVER, 1999). Rapid progress in forest biology and quantitative sciences supported a widespread acceptance of a high-yield agricultural paradigm for forestry. Research emphasis shifted away from natural regeneration and growing stock levels to high-yield practices such as site preparation, planting, early vegetation management, and thinning. Many of these studies were (or are) long-term in nature (e.g., CURTIS and MARSHALL, 1997; WAGNER et al., 2004), but owing to uniform stand structures and monoculture compositions, large, stand-scale compartments were no longer necessary for study. Plot sizes of 0.1 ha or less, two orders of magnitude smaller than the 10-ha units in the old compartment studies, allowed field studies to examine numerous treatments without sacrificing adequate replication. Research administrators and many scientists came to regard compartment studies as costly, low-power experiments on the wrong topics, diverting resources away from high-yield studies. Compartment studies soon fell into disfavor, and many studies were either closed or neglected for decades.

The force of this paradigm shift led the profession away from a broad view of silviculture. Research emphasized various elements of plantation forestry, to considerable effect. Arguably, the two most influential advances in American silviculture during the last half of the 20' century were the advances in genetically improved planting stock and the development of herbicides that act very specifically in small doses to interfere with physiology and biochemistry of woody plants. These effective agronomic technologies became so closely associated with clearcutting that silvicultural systems using other regeneration methods were neglected and often derided. As a consequence, experimentation with silvicultural systems other than those associated with intensive forestry was so infrequent that scientists who did engaged in it were regarded as iconoclasts. Advances in such alterative systems from this period were typically limited to new analyses of the older studies, as well as reports on unreplicated demonstrations over a longer term than is typically observed (e.g., MURPHY, 1983; BAKER, 1986).

2.3 The Era of Ecological Forestry: 1990-Present

By the late 1980s, growing reservations about the effect of widespread application of the even-aged production forestry model on natural ecosystems and controversy over harvest of old-growth prompted another shift in silvicultural paradigms focused on US National Forests. Much of this drama was played out in numerous court battles. In the Pacific Northwest, harvesting was effectively stopped on federal lands and a presidential summit was convened to resolve the conflicts in managing national forests. The result was the development of the Northwest Forest Plan (UCHMANN et al., 1996). Many of the ideas used in developing this plan and influencing new management directions across the United States were stimulated by Franklin's (1989) plea for a "new" forestry and Hunter's (1990) influential book that introduced biodiversity to a skeptical profession in a non-threatening package. On public forests, a more naturally focused silviculture was again in vogue, and diversity in stand structure and composition became important management objectives.

Although it may be tempting to describe this as the pendulum swinging back to the 1930s, this new era of ecological forestry *(sensu* SEYMOUR and HUNTER, 1999) is quite different in several respects. As the earlier quote from BAILEY and SPOEHR suggests, scientists of the 1920s favored natural regeneration and conservative treatment of the growing stock because of its inherent economy in meeting production targets; they could not anticipate the prosperity of the 1960s and the willingness of private landowners to invest in costly agronomic practices simply to grow trees. In contrast, the contemporary incarnation of natural-stand forestry is founded heavily on disturbance ecology, under the belief that operating within nature's limits (the historical range of variability concept) is a conservative way to manage for biodiversity (the coarse-filter concept) (SEYMOUR and HUNTER, 1992; FRANKLIN et al., 1997). A prominent element is the restoration of ecological processes, such as prescribed burning or partial disturbance events emulated by silvicultural practices in systems other than clearcutting. Socio-political issues were also quite influential; regardless of how "natural" stand-replacing disturbances might be in a given forest's historical disturbance regime, their ecological mimicry via large-scale clearcutting was simply unacceptable to a growing number of public stakeholders.

Perennially important issues such as stand production, growing stock levels, and investments in cultural treatments are not commonly mentioned, or are discussed in association with other commodity and non-commodity forest derived benefits. The fact that revenues from timber production can sponsor practical implementation of systems developed as alternatives to clearcutting, especially those based on ecological restoration (GULDIN et al., 2004), is less commonly discussed.

3. CONTEMPORARY LARGE-SCALE SILVICULTURAL EXPERIMENTS

Beginning in the early 1990s, the emergence of ecological forestry and urgency for alternatives to clearcutting on public forests began to spawn new large-scale experiments designed to address a comprehensive suite of silvicultural systems rather than just treatments. This need was particularly acute in the Pacific Northwest, which had no such existing experiments to resurrect (MONSERUD, 2002). Although partial cutting was practiced there during the 1930s as in other regions, and the method received a certain early acclaim (KItKLAND and BRANDSTROM, 1936), experimental assessment was limited to unreplicated post-harvest monitoring plots that were abandoned after only a decade (CURTIS, 1998).

To illustrate the features of these new experiments, we review and contrast one example from four regions in the United States:

1. The Acadian Forest Ecosystem Research Program (AFERP): mixed northern conifer forest of east-central Maine; established 1994 and administered by the University of Maine; located on the Penobscot Experimental Forest (SAUNDERS and WAGNER, 2005; SEYMOUR, 2005).
2. Restoring Complex Structure and Composition in Great Lakes Pine Ecosystems (RSCP): second-growth red pine forests in Minnesota; established 2001 and administered by the USDA Forest Service, North Central Research Station; located on the Chippewa National Forest (PALM and ZASADA, 2003; PALM et al., 2005).
3. Ouachita Mountains Ecosystem Management Research Project (OMEM): shortleaf pine-hardwood forests in Arkansas; established 1992 and administered by the USDA Forest Service, Southern Research Station; located on the Ouachita and Ozark-St Francis National Forests (GULDIN, 2004).
4. Silvicultural Options for Young-growth Douglas-fir Forests (SOYDF): second-growth coastal Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco); established 1998, administered jointly by the Pacific Northwest Research Station and Washington State Department of Natural Resources; located originally on the Capitol State Forest in Washington (CURTIS et al., 2004) and recently replicated on Vancouver Island (British Columbia, Canada) as part of the Silviculture Treatments for Ecosystem Management in the Sayward (STEMS) study (DE MONTIGNY, 2004).

3.1 Objectives

Although each study has many detailed objectives, two overarching goals seem to drive these studies. The null hypothesis of the SOYDF and OMEM studies, both of which include a full suite of common American silvicultural systems, is that regeneration success of the favored shade-intolerant species [Douglas-fir, shortleaf pine *(Pinus echinata* Mill.) under various systems of partial overstory retention does not differ from that of clearcutting. This reflects silviculture's first principle of sustainability: no regeneration method can be considered successful if it cannot reproduce the dominant or desired overstory species. In contrast, the AFERP and RSCP studies address the issue of active ecological restoration, in which all treatments are hypothesized to accelerate restoration of structural and compositional diversity in forest types simplified from past human activity (PALIK and ZASADA, 2003; FRIEDMAN and REICH, 2005).

3.2 Experimental Design and Treatments

All studies use the time-tested randomized complete block design with all treatments represented at a single location *(Table I).* Treatment units are large (10-30 ha) and were randomly assigned within each block. The SOYDF and OMEM studies envision inference at the regional scale, with replicates installed throughout the forest type in question. The RSCP and AFERP studies are more narrowly focused geographically, with replicates only in a single forest. Replication is necessarily minimal (3-4), limited by the cost of installing and monitoring the large area in each experiment (90-780 ha).

All studies include commonly suggested alternatives to clearcutting and employed overstory retention during harvest: specifically, structures with uniformly dispersed overwood trees are compared against spatially aggregated patterns involving regeneration in gaps of various sizes *(Table* 2). Retention of mature trees and other biological legacies at harvest (FRANKLIN et al., 1997; MITCHELL et al., 2004) has been widely advocated in North America as a key approach for sustaining or restoring structural complexity (e.g., WATANABE and SASAKI, 1994; LARSEN, 1995; SULLIVAN et al., 2001; VANHA-MAJAMAA and JALONEN, 2001; MITCHELL and BEESE, 2002; BEESE et al., 2003; PALM. et al., 2002; AuERY et al., 2004; BEBBER et al., 2004; BRAvo and DIAZ-BAutwo, 2004; HALPERN et al., 2005). Retention management approaches reflect the fact that natural post-disturbance stands often display more complex structure than is typical after traditional clearcuts (LINDENMAYER and FRANKLIN, 2002), with a spatially heterogeneous landscape that includes living trees, dead wood, and undisturbed patches of understory. This diversity provides the context for regeneration and continuity of ecological functions in the developing stand (FRANKLIN and MACMAIION, 2000; FRANKLIN et al., 2000).

The SOYDF and OMEM studies include delayed regeneration treatments (thinnings) as well as conventional clearcuts, thereby

Table 1

General Study Design.

Merkmale der Versuchsanlagen.

Study	Forest Type	Year(s) Established	Experimental Design	Treatments (incl. control)	Blocks (replications	Size of. Treatment Unit (ha)	Total Area in Experiment (ha)
Silvicultural Options for Young-growth Douglas-fir (SOYDF)	Coastal *Pseudotsuga menziesii*	1998-2004	Randomized Block	**6**	3	13-29	300
Ouachita Mountains Ecosystem Management Research Project (OMEM)	*Pinus echinata* - hardwoods	1992	Randomized Block	13	4	15	780
Restoring Complex Structure and Composition in Great Lakes Red Pine Ecosystems (RSCP)	Lake States *Pinus spp.*	2001	Randomized Block	4	4	16	259
Acadian Forest Ecosystem Research Program (AFERP)	Mixed northern conifers-hardwoods	1995-97	Randomized Block	3	3	10	90

Table 2

Treatments Included.

Behandlungsvarianten.

Study	Clearcut	Untreated Control	Dispersed Retention	Gaps or Patches	Single-tree Selection	Thinning (Delayed Regeneration)
SOYDF	Yes	Yes	Yes	Yes (2 sizes)	No	Yes
OMEM	Yes	Yes	(2) Uniform shelterwood, Seed tree	Yes	Yes	Yes
RSCP	No	Yes	Yes	Yes (2 sizes)	No	No
AFERP	No	Yes	PEF[1]	Yes (2 sizes)	PEF[1]	PEF[1]

[1] Treatment replicated twice in nearby compartment study on the Penobscot Experimental Forest.

providing a full suite of common North American silvicultural systems. Because clearcutting has been the proven regeneration method for these species, the inclusion of this treatment represents another form of "control" against which to benchmark regeneration success under alternative treatments. Clearcutting was considered for inclusion into the RSCP study, but was dropped because the interest of the Chippewa National Forest was specifically to evaluate alternatives to this method, as well as the fact that regeneration response of the target species *(Pinus resinosa, P. strobus, P. banksiana)* to clearcutting has been thoroughly studied (BLAKE and YEATMAN, **1989; WEBER et al., 1995; Prrr** et al., 2000). AFERP does not include a clearcut treatment because this regeneration method is not recommended for most species of the Acadian forest (SEYMOUR, 1995).

Unlike the compartment studies during the selective cutting era, all modern experiments include randomly assigned untreated controls. Historical reconstructions at each site reveal that these untreated units are themselves former clearcuts; as such, they represent early- to mid-successional vegetation structures, and presently do not include all of the structural elements of late-successional old-growth in their respective forest types. In the short term, unmanaged units represent closed-canopy conditions that are valuable for a myriad of experimental purposes; in the long-run, they are intended to provide examples of natural successional pathways, and thus serve as benchmarks against which active silvicultural interventions can be compared ecologically. The latter role is especially critical in the RSCP and AFERP experiments where treatments have a strong restoration theme and are explicitly designed to accelerate development of late-successional, ecologically complex conditions.

All modern experiments also include treatments in which regeneration is concentrated in small gaps or patches that occupy 10-40% of the unit *(Table 3).* In the RSCP study the matrix was also underplanted experimentally to evaluate seedling response to a range of densities. Because historical silvicultural systems and experiments in the United States have tended to stress uniform stand treatments, gap cuttings are perhaps the most original and innovative ones in these modern experiments. Three studies explicitly vary gap size in two contrasting treatments; the OMEM study includes a range of gap sizes within its group selection treatment. In all but one case, the matrix between gaps was also treated at the time of gap creation by **various prescriptions shown** in ***Table*** *3;* all would be considered fairly standard ways to treat stands uniformly if the gaps were not a part of the prescription. In addition, the matrix in the SOYDF study will be reduced on a 10-year cutting cycle. Finally, note that gaps were planted in two studies; the other two rely on natural regeneration.

The within-stand patchiness induced by gap harvests complicates monitoring in ways not apparent with uniform treatments. The problem stems from the systematic grids which are used to locate permanent monitoring plots prior to any treatment marking. We assume such a sampling pattern is unbiased with respect to the original uniform overstory; however, gaps or patches may also be located quasi-systematically in order to distribute them throughout the stand. Moreover, in practice, gaps are often located based on silvicultural objectives such as releasing accidentally established advance growth, restoring locally understocked conditions, or harvesting groups of surplus trees relative to structural targets. In addition to these possible sources of bias, the sampling intensity is designed to give adequate precision on overstory phenomena over the entire area, and is thus inadequate for the small fraction of the stand in gaps. One solution lies in measuring gap areas, creating two distinct strata, and computing weighted treatment means to quantify the overall stand response. However, this does not adequately capture the response of seedlings to well-known ecological gradients within gaps (distance from edge relative to stand height, position within the gap); such information requires a sampling system that explicitly addresses these factors.

All studies include retention of reserve trees in dispersed patterns *(Table 4);* typically between 10-20% of the pre-harvest stand basal area is reserved either permanently (AFERP, OMEM) or harvested after one 60-year rotation (SOYDF). The RSCP study retains a much higher density of reserves (basal area = 16 m^2 ha^{-1}), the fate of which will be decided after 60 years with no cutting. The OMEM study retains 4.6 m^2 ha-' of reserve-tree basal area in both the shelterwood and seed-tree treatments; seed trees are simply left standing after a 10-year regeneration period, at which point shelterwood overwoods are reduced to a final seed-tree density. The AFERP experiment retains reserve trees within **gaps;** about 4 m^2 ha-' (10%) is designated for retention as the gaps are created and expanded. Some gaps in the OMEM also retained 2-3 m^2 of residual hardwoods for mast production.

Biodiversity is monitored to varying degrees in all studies, although no study consistently has had the resources to track a comprehensive suite of organisms routinely *(Table 5).* Such multidisciplinary studies are costly *(Table 6),* and often require expertise beyond that of the administering agency. Studies that monitor animal taxa appear to have higher annual monitoring costs than those

Table 3
Details of Gap/Patch Treatments.
Details der Lochvarianten.

Study	Gap Sizes (ha)	Area in Gaps (%) per Entry	Cutting Cycle (years)	Gap Regeneration. Method	Matrix Treated?
SOYDF	.04 - 0.6 0.6 - 2.0	20%	15	Planted	Thinned to 45% relative density
OMEM	0.2 - 0.8	17%	10	Natural	Target reverse-J dbh structure
RSCP	0.1 0.3	30-40%	60	Planted (3 Pinus **spp.)**	Thinned from below, such that entire area averaged **16m²**/ha basal area (incl. gaps)
AFERP	0.1 0.2	10% 20%	10	Natural	One-time improvement cutting in 20% treatment only. None in 10% treatment.

Table 4

Details of Dispersed Retention Treatments.

Details der verteilten Retentionsvarianten.

Study	"Label"	Level of Retention (Basal Area)	Long-term fate of reserve trees
SOYDF	Two-aged	20% (=37 trees/ha)	One rotation of young cohort
OMEM	Seed-tree	4.6 m^2/ha	Seed trees retained permanently
	Shelterwood	9.2 m^2/ha	Shelterwood overwood reduced by 50% after 10 years, then retained permanently
RSCP	Dispersed Retention	16 m^2**/ha**	**One rotation** of young cohort (60 years)
AFERP	Irregular Group Shelterwood with Reserves *(Femelschlag)*	10% (= 4 m^2/ha)	Selected when overwood is removed from regenerating 0.2 ha groups; retained permanently.

Table 5

Elements of Biodiversity Monitored.

Elemente des Biodiversit$is-Monitoring.

Study	Herbac. Veg.	Coarse Woody	Birds	Amphib.	Invert.	Other
SOYDF	Routine	Blowdown **events only**	Ad-hoc	No	No	
OMEM	***Ad-hoc***	***Ad-hoc***	**Routine**	**Routine**	***Ad-hoc***	
RSCP	Routine	Routine	**Routine**	***Ad-hoc***	***Ad-hoc***	**Routine: Various insects and pathogens**
AFERP	Routine	Routine	***Ad-hoc***	***Ad-hoc***	***Ad-hoc***	

limited to plants, although the sheer size of the experiment is obviously also a major determinant.

3.3 Replication and Statistical Power

Although large-scale studies are very expensive, our experience suggests that stand-scale treatment units are essential for studying any silvicultural treatment that purposely creates within-stand diversity, whether it be single-tree selection to a diameter structure or a gap-based system. Consider a gap treatment that creates 0.4 ha openings over 20% of the stand in each of a series of five entries. Such a system "repeats" every 2 ha within the stand, so stands must be 10-20 ha in order to have multiple repetitions of the pattern. Replicates of only 2-ha in this case would be overwhelmed with "edge effects" as they abutted other treatments, analogous to installing a 20% thinning treatment by removing one tree on a five-tree plot. Furthermore, stand-scale units help ensure that treatment technologies will be feasible and costs will be realistic if such systems are embraced operationally. Finally, treatment units must be large enough to encompass the home ranges or territories of keystone animal species that serve as important indicators of biodiver-

Table 6

Study Costs.

Kosten der Versuchsanlage.

Study		Establishment (includes planting, veg. management)	Annual Measurements and Maintenance
	SOYDF	$ 312,000	$7,500
	OMEM	$ 1,000,000	$ 300,000
	RSCP	$1,000,000	$120,000
	AFERP	$120,000	$30,000

sity. If it were not for this last issue, one could argue that clearcut and uniform dispersed retention treatments could be represented in much smaller units.

Although such large treatment units obviously work against adequate replication, the need to study silvicultural systems and ecological phenomena at appropriate scales leaves silviculture scientists no choice. Although testing null hypotheses at an arbitrary probability of 0.05 often seems inviolate in such experiments that follow the classic randomized block model, this issue may be worth revisiting in cases where replication is so expensive. For example, it is interesting to consider the consequences of a Type II error - failing to reject the null hypothesis owing to low power from insufficient replication and perhaps high variability. In the SOYDF and OMEM studies, such an error might take the form of a finding whereby some parameter of regeneration success under certain overstory retention or gap treatments is not different statistically from the proven method of clearcutting. Users predisposed to abandoning clearcutting would immediately embrace alternatives with a false confidence, only later to find that the alternatives experienced regeneration problems. In the AFERP and RSCP studies, a Type II error might conclude that certain gap treatments had no negative effect on songbird nesting relative to the untreated control; managers would then proceed with gap harvests that may have negative effects, Now, imagine if the test had been done at p = 33 instead of .05 and **had** suggested differences; what would managers do in these cases? It is at least possible that they would respond differently, thus illustrating the importance of choosing rejection probabilities that are realistic given the context of the expected effect size and costs of alternative actions.

3.4 Strengths of Large-scale Studies

Beyond the necessity of treating entire stands and monitoring at ecologically appropriate scales, large-scale studies have other benefits. When scientists work at the same scale as managers, researchers gain appreciation for operational realities such as limitations of harvesting systems and costs of planting and tending treatments. The joint ownership resulting from partnerships between scientists and managers has immeasurable value in bringing credibility and relevance to the research (MARSHALL and CuR'ris, 2005). Study sites provide "life-sized" examples of innovative silvicultural systems, which help convince managers of their operational feasibility and provide a training ground. Finally, installations offer great field laboratories for non-silviculturists to study ecological phenomena in the context of well documented and professionally executed silvicultural systems. Examples include small-scale studies of gap regeneration, salamander dispersal, wood decomposition, tree ecophysiology, whole-stand studies of avian population ecology, nutrient cycling, remote sensing, and public perceptions.

4. CONCLUSIONS

Long-term, large-scale silvicultural experiments, both old and new, are critical chapters in American forestry. Since the 1920s, treatments included in these experiments constitute the best attempts of the nation's top research silviculturists to address the pressing problems of each region and time period. Without them, the profession would lack the essential scientific framework that is central to forest sustainability at all levels. Finally, silvicultural research, like any other applied discipline, has no value unless it is **used.** Although sound science is essential, our experience suggests that convincing skeptical managers to embrace novel ideas and practices is as much a marketing challenge as it is a scientific one. Without these operationally oriented laboratories of managed forest vegetation designed to illustrate the choices available to managers, we would have little to offer beyond anecdotes and opinions extrapolated from small-scale narrowly focused studies.

5. ABSTRACT

This paper reviews experience and research findings from selected large-scale, long-term silvicultural experiments in four regions of the United States: the Northeast, the Lake States, the mid-South, and the Pacific Northwest. As early as the 1920s, when there was nationwide interest in multi-aged silviculture, researchers recognized that silvicultural systems involving within-stand variation in age and size structure could not be tested effectively on small (<1 ha) plots, and began installation of compartment-scale (10-20 ha) trials on many experimental forests throughout the United States. Large-scale trials have experienced a revival in the past decade for several reasons: a search for alternatives to clearcutting that successfully regenerate shade-intolerant species; a renewed interest in managing for within-stand structural complexity, and a need to test hypotheses about biodiversity that occur at the scale of entire forest stands. Jarge-scale experiments are difficult and expensive to install, properly replicate, monitor, and maintain over time, but also have many benefits: (1) scientists learn to appreciate operational realities of forest managers, such as limitations of harvesting systems; (2) study sites provide "life-size", realistic examples of innovative silvicultural systems, and thus are more readily understood and embraced by practitioners; and (3) installations offer great field laboratories to study a wide range of questions from small-scale phenomena, such as amphibian dispersal and seedling development, to whole-stand responses in the context of a well-documented and professionally executed silvicultural systems.

6. Zusammenfassung

Titel des Beitrages: *Groiflfichige, langfristig angelegte waldbauliche Feldexperimente in den USA, historische Ubersicht and gegenwdrtige Beispiele.*

Dieser Beitrag berichtet fiber Erfahrungen and Forschungsergebnisse ausgewahlter langfristiger waldbaulicher Feldversuche in vier Regionen der Vereinigten Staaten von Nordamerika: im Nordosten, im Gebiet der Groben Seen, im Mittleren Suden and im Pazifischen Nordwesten. Bereits in den 20er Jahren des letzten Jahrhun-

derts, als man sich iiberall in den USA far Dauerwaldsysteme interessierte, erkannten Forscher, class kleinflachige Versuchsflachen (<1 ha) nicht ausreichten, urn waldbauliche Behandlungen in ungleichaltrigen Mischwaldern zu beurteilen. Daher wurden bereits damals uberall in den USA in zahlreichen Versuchswaldern (experimental forests) Versuchsflachen von AbteilungsgroBe *(10-20* ha) eingerichtet. Grol3flachige Feldversuche erlebten wahrend der letzten zehn Jahre aus verschiedenen Grunden eine Renaissance: die Suche nach Altemativen zur schlagweisen Nutzung, die eine Verjangung lichtbediirftiger Arten gewahrleisten; das erneute Interesse an der Schafftmg von bestandesweiser Strukturdiversitat, sowie die Notwendigkeit, Hypothesen zur Biodiversitat auf Bestandesebene zu testen. Grollflachige Feldversuche sind kostspielig. Ihre Anlage, die zweckmaBige Anordnung von Wiederholungen, die Oberwachung and der Unterhalt sind aufwandig, aber sie habeas viele Vorziige: (1) Wissenschaftler bekommen einen Eindruck von der Realitat im Management, wie z.B. von den begrenzten Moglichkeiten der Holzernte-Systeme; *(2)* die Versuchsflachen bieten lebendige und realitatsnahe Beispiele innovativer Waldbauverfahren, die von Praktikern leichter verstanden and akzeptiert werden; (3) die installierten Messstationen sind niitzliche Feldlabore, die zahlreiche Moglichkeiten zur Untersuchung von kleinskaligen Fragestellungen, wie die Verteilung von Amphibien and Samlingen, bis zu grolskaligen Bestandesreaktionen auf gut dokumentierte und fachkundig durchgefahrte Waldbauverfahren bieten.

7. Resume

Titre de Particle: *Experiences de sylviculture a long terme et sur des grandes surfaces aux U.S.A. Aspects historiques et exemples contemporains.*

Cet article conceme les experiences et les resultats des recherches de sylviculture poursuivies au champ et sur le long terme dans 4 regions des USA: au nord-est, dans la zone des grands laPs, au centre du sud et au nord-ouest, sur la cote du Pacifique. Deja, dans les annees 20 du siecle dernier, **alors que partout aux** U.S.A. on portait interet a un systeme de foret durable, les forestiers s'etaient rendus compte que des petites placettes experimentales (< 1 ha) ne suffisaient pas pour porter un jugement sur les traitements sylvicoles clans les forets melangees inequiennes. En consequence, on a installe, des cette epoque et partout aux U.S.A., des placettes experimentales ayant la surface d'une parcelle (10-20 ha) dans de nombreuses forets dices d'experience (experimental forests). Ces recherches sur un terrain de grande surface ont vecu, pour diverses raisons, un veritable renouyeau au cours des dernieres decennies = recherche d'altematives a la coupe a blanc **assu**rant la regeneration naturelle des essences de lumiere, le desir renouvele d'assurer une structure diversifiee aux peuplements les hypotheses a tester en ce qui concerne la biodiversite an niveau du peuplement. Ces dispositifs etendus sont coateux. Leur installation, le programme judicieux de repetitions, la surveillance et 1'entretien ont des coats, niais les avantages sont nombreux =

1) les scientifiques acquierent tine idee de la realite dans le management, comme par exemple des possibilites reeiles des systemes de recolte des bois;

2) les parcelles experinientales constituent des exemples vivants et proches de la realite de methodes de sylviculture innovantes qui seront ainsi mieux comprises et plus facilement acceptees par les praticiens;

3) les stations de mesures qui sent installees sont d'utiles « laboratoires de terrain>> qui offrent de nombreuses possibilites de recherches sur des questions qui se posent soit a petite &Ilene, comme la distribution des amphibiens ou des semis, soit a grande echelle lorsqu'il s'agit des reactions des peuplements a des methodes de sylviculture bien etudiees et mises en eeuvre avec competence. J. M.

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