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PLANT COMMUNITY RESPONSES TO HARVESTING AND POST-HARVEST MANIPULATIONS IN A *PICEA - LARIX - PINUS* WETLAND WITH A MINERAL SUBSTRATE

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Abstract: Forested wetlands in the Northern Great Lakes Region are becoming increasingly used as a timber resource. Yet, limited information is available on the effects of harvesting and post-harvest manipulations (site preparation and fertilization) on tree and ground vegetation in these wetland communities. The objective of this study was to examine production changes and species diversity in the vascular plant community four years after a forested, mineral wetland in Northern Michigan was whole-tree harvested, site prepared (bedded or trenched), and fertilized (N, P, N + P). The wetland had an original overstory of black spruce (*Picea mariana*), tamarack (*Larix laricina*), and jack pine (*Pinus banksiana*), with a significant cover of *Sphagnum* and Ericaceous shrubs. Site preparation techniques were done immediately after harvesting. The site was then planted with jack pine seedlings (1–0 stock). Fertilization occurred four years after harvesting and site preparation. Results indicate that trees in bedded areas with N fertilizer applied had significantly greater total seedling height, basal diameter, and height increment when compared with those from harvest-only or trenched areas. On harvest-only areas, seedling production was greater with P and N + P fertilizers than with N fertilizer alone. Fertilizer responses were attributed to which type of site preparation (bedding versus trenching) was used and the degree of organic matter and *Sphagnum* incorporated into the mineral soil. Only site-preparation treatments (not fertilization treatments) had significant effects on numbers and cover of vascular plant groups (woody, herbaceous, and grass/sedge). Number of species and total cover of all vascular plants were significantly greater on the harvest-only areas than on trenched, bedded, or uncut areas. As expected, relative cover of the grass/sedge group increased with increasing site disturbance (bedded and trenched), mainly due to disturbance and lack of the thick *Sphagnum* mat When compared to the adjacent uncut area, relative cover of herbaceous species was significantly reduced on treated areas. In future years, if the significant effects of manipulation treatments on tree productivity and vascular plants continue, the resulting community may be different than the successional sequence witnessed by the original forest. This will, however, depend on the rate of crown closure and the invasion of bryophyte species.

Key Words: jack pine, mineral wetland, northern forested wetland, community diversity, harvesting, site preparation, fertilization, bedding, trenching, Northern Michigan

INTRODUCTION

Forested wetlands are a significant resource in the Great Lakes Region, not only for their hydrologic functions and biotic diversity but also for their timber production. In Michigan alone, over 20 percent of the commercial forest lands have been classified as wetlands (Smith and Hahn 1987). Until recently, the commercial use of these wetlands had been limited due to the cost of harvesting on wet areas. However, due to increased wood demand, the use of these communities as a timber resource has increased.

In the Lake States, forested wetlands with a mineral subsoil have been heavily used as a timber resource. This has been due to *i*) their greater productive capacity and *ii*) their commercial operability during winter months when compared with peatland communities. These mineral wetlands comprise plant communities unique to local and regional landscapes and are therefore an important resource not only for their timber but also for their community structure and diversity. Very little is known about the response of these wetlands to whole-tree harvesting and post-harvest site preparations, such as bedding, trenching, and fertilization.

Many studies in Europe (Paivanen 1982, Paavilainen and Paivanen 1988, Laine et al. 1992, Sutton 1993) and in North America (Benzie 1963, 1977, Morris et al. 1978, Verry 1986, Hillman 1987, Brumelis and Carleton 1989, Sutton 1993, Akerstrom and Hanell 1996) have summarized the effects of harvesting, pre- and post-harvest manipulations (drainage, trenching, bedding, mounding), and/or fertilization on tree production in forested peatlands. Specific studies in northern regions indicated increased tree growth response when peatlands were drained and/or fertilized (Weetman 1975, Alban and Watt 1981, Hillman 1987). However, due to past ecological concerns and "no net loss" policies in the United States, drainage has been dropped as a viable alternative for increasing tree production on forested wetlands. Other methods, such as trenching and bedding (mounding) (Figure 1), have become significant substitutes for drainage (Sutton 1993). Beds are usually created by equipment that berms mostly organic material into small banks of soil: mounds are created by equipment (usually a backhoe) that deposits larger amounts of organic and mineral soil into larger banks of soil, creating a mound and an adjacent hole. Some information is presently available on the effects of these treatments on soil characteristics for mineral wetlands (Trettin and Jurgensen 1992, Trettin et al. 1993, 1995, 1996, McLaughlin et al. 1996). Trettin and Jurgensen (1992) and Trettin et al. (1993, 1995) described significant reductions in soil carbon due to harvesting and post-harvest site preparations (trenching and bedding) on the site used in this study.

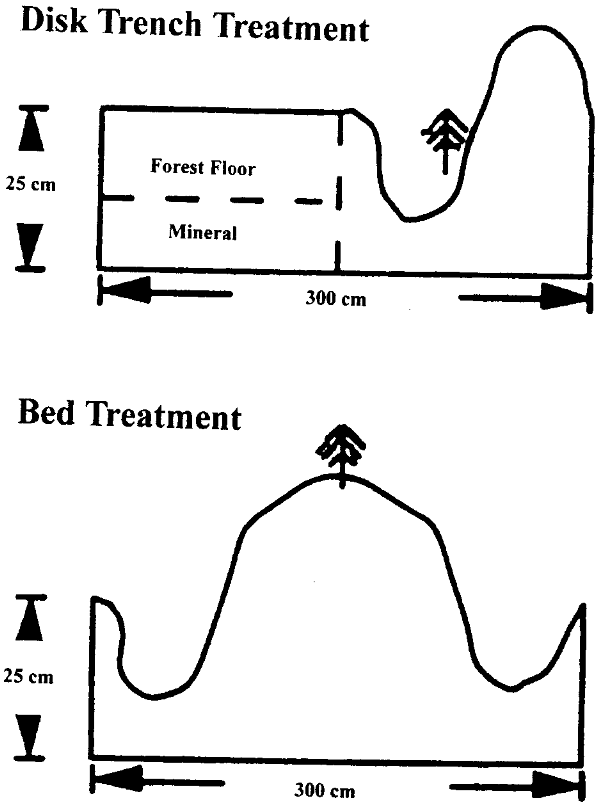

Figure 1. Cross-sectional depiction of disk-trenched and bedded treatments and planting position of seedlings.

One would expect reductions in soil C to be tied to reductions in plant production for mineral wetlands. Yet, on Southern Coastal wetlands, Burger and Kluender (1982) described significant reductions in tree production after age 10 due to the removal of organic residue; yet, before age 10, increased tree production was observed on these areas. Increased production before age 10 was attributed to increased decomposition rates, release of available nutrients, and reduced competition. Such information on the effects of harvesting and site preparations on northern forested wetlands is not presently available. While some information from drainage and peatland studies can be applied to bedded (mounded) or trenched mineral wetlands, little, if any, information is available on changes to the overall plant communities.

The purpose of this study was to determine whether harvesting, site preparations (bedding and trenching), and fertilization (nitrogen (N) and phosphorus (P)) significantly affect seedling growth and vascular plant numbers and cover on a northern forested wetland with a mineral substrate. The specific scientific hypotheses tested were:

1) harvesting with site preparations (bedding or

tioned and measured diagonally across the three uncut subplots. A total of 159 microplots were measured; 144 were used to investigate the influence of site preparation and fertilizer on vascular plants, while 15 additional microplots were used in conjunction with the 144 microplots to compare vascular plants between the uncut area and the site-prepared and fertilized areas.

Statistical Analyses

Due to inherent differences in light regimes and organic matter disturbance between harvested and unharvested areas, we assumed differences in individual species cover would occur. To capture a broader and more comprehensive picture of community responses, we assessed differences in community richness, total cover, and relative cover for the above-mentioned groups. Braun-Blanquet cover classes were used to estimate cover. The geometric mean for each class was used in the statistical analyses.

A two-way analysis of variance with interactions was used to test whether mean basal diameters, total heights, and height increments (for years 1990, 1991, 1992) were significantly different due to site-preparation and fertilization treatments. If found significantly different, means were compared using Student-Newman-Keuls multiple comparison test. Due to significant heterogeneity of variance in vascular plant measurements, a nonparametric test (Kruskal-Wallis statistic) was used to evaluate mean differences. The Z values from the Kruskal-Wallis multiple comparisons test were used to compare means.

RESULTS AND DISCUSSION

Tree Seedling Production

Site preparation and fertilizer treatments had a significant interacting effect on seedling diameters and heights. Basal diameters were significantly greater on N fertilized, bedded, and trenched treatments than on other treatments (Figure 2). These results were attributed to a higher concentration of organic carbon on bedded and trenched areas. McLaughlin et al. (1996) reported 30% higher C in the forest floor and 20% higher C in the mineral soil on bedded versus harvest-only areas in this wetland. However, due to increased temperatures and N decomposition rates, also attributed to bedding and trenching (Trettin and Jurgensen 1992), N may have leached readily from these areas, creating a more N-limiting area than harvest-only areas. A different result on the trenched areas may have occurred if seedlings had been planted on the upturned organic layer instead of on the side of the trench, as done in this study (Figure 1).

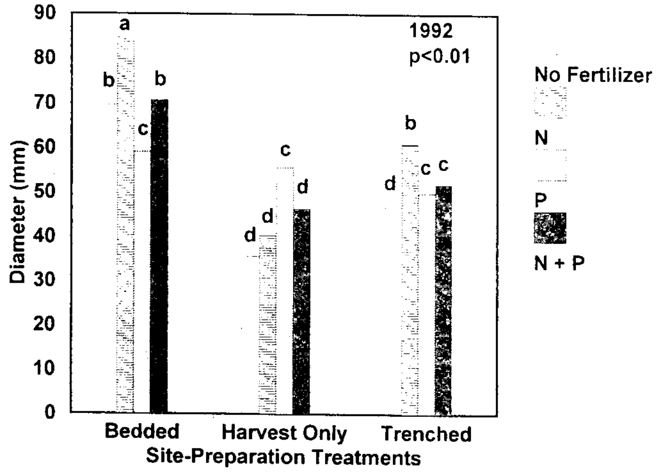

Figure 2. Mean basal diameters of jack pine seedlings by site-preparation and fertilization treatments. Significant different means (F statistic 8.105; 6,1011 d.f.) are indicated by letters at the top of each bar; significantly different means are indicated by different letters.

The P fertilizer produced significantly greater seedling diameters than other fertilizer treatments on the harvest-only treatments (Figure 2). Because of closer proximity to the water table and slower N decomposition rates, the harvest-only treatment may not have been as N-limited as the bedded and trenched treatments. Increased levels of available P may also have occurred due to P release in the more readily-available, decomposing *Sphagnum* (Koerselman et al. 1993) in harvest-only areas and to increased P mineralization rates due to fertilization (Pritchett and Comerford 1982, Allen and Campbell 1988, Polglase et al. 1992).

Significant differences in total heights were also observed. Although ranked means for total height were the same as basal diameters, bedded areas with N or N + P fertilizers, as well as unfertilized treatments produced similar total seedling heights (Figure 3). Only in trenched areas with N and N + P fertilizers were seedlings significantly taller than seedlings in unfertilized and P-fertilized areas (Figure 3). On the harvest-only area, P and N + P fertilizers significantly increased seedling heights relative to the unfertilized and N-fertilized areas (Figure 3). Reasons for these results are unclear at this time.

Comparison of height increments from 1990 to 1992 indicated the dynamic effects of site preparation techniques and the "instantaneous" effect of fertilizers (Figure 4). Before fertilization (yrs 1990 and 1991), similar height growth increments were observed (Figure 4A and 4B). Few significant (F statistic 3.711; 6, 1011 d.f.) differences were observed on harvest-only and trenched treatments in 1990 and were attributed to *i*) differences in initial seedling characteristics, *ii*) acclimation of seedlings to a certain area, *iii*) initial and Krause (1985) verified the importance of water-table depths [drainage class] for jack pine height growth but somewhat contradicted Wilde and Zicker (1948) findings, mainly because of their use of a linear versus a curvilinear model as used by Wilde and Zicker (1948). Based on the linear model, Hamilton and Krause (1985) found an inverse relationship between drainage class and height growth intercepts (2-, 3-, and 4-yr).

Bedding and trenching, while providing ideal microsites for planted seedlings, can also decrease competition from ground vegetation (Sutton 1993). Past research by Hamilton and Krause (1985) and Wilde (1970) demonstrated reduced jack pine growth with increased Ericaceous cover/presence. Weetman and Fournier (1984a) also determined significant increases in growth with straw applications in a 45-year-old jack pine stand growing on a deep outwash sand. Straw applications effectively reduced competition from understory (Ericaceous) plants and added high C/N ratio material, improving N conditions on the site. Most, if not all, prior studies on jack pine have demonstrated the importance of fertilizers in improving jack pine growth in semi-mature to mature stands (Benzie 1977, Morrison et al. 1981, Krause et al. 1983, Weetman and Fournier 1984a, 1984b). Very little information was available on fertilizer responses for young jack pine stands. Weetman and Fournier (1984b) attributed the lack of responses in certain aged stands to the N source and amount, individual stand dynamics, and the temporary response of older trees to one-time applications. In this study, jack pine seedlings responded significantly to fertilizers, especially in combination with site preparation. It is difficult to determine whether these responses will continue (Kaunisto 1982); however, fertilized jack pine seedlings planted on beds have a distinct advantage at age four over seedlings planted on harvest-only areas and trenched areas.

Vascular Plant Numbers and Cover

Fertilization did not significantly ($p>0.05$) affect vascular plant numbers and cover. Although others have observed vascular plant responses due to fertilization on dry-site jack pine stands (Abrams and Dickman 1983), this was not the case on this mineral wetland. Mackun et al. (1994), however, found that only 6 of 64 wetland species were affected by liming and suggested that ground-vegetation species have "broad ecological amplitudes" when exposed to short-term shifts in pH or nutrient release. Still, very little information is available on the effects of nutrients/fertilization on vascular plants growing on peatlands (Bridgham et al. 1996) or on mineral wetlands. In this study, high rates of tree seedling growth, and thus nutrient uptake, may have significantly reduced vascular plant responses to fertilization. Therefore, due to the lack of fertilizer responses, the following discussion will only describe differences in vascular plant numbers and cover among site-preparation treatments and the uncut area.

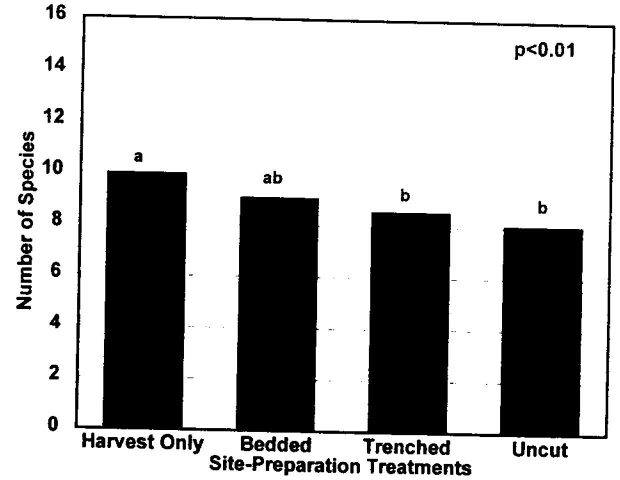

Figure 5. Average number of species by site-preparation and fertilization treatments. Significant different means are indicated by letters at the top of each bar; significantly different means are indicated by different letters.

The total number of vascular species observed on all plots was 44; 20 were trees (30%) and shrubs (woody) (70%), 17 sedge and grasses, and 7 herbaceous. Of the woody species only 45% were considered faculative wetland or obligate wetland species; these were mainly shrub species. Ninety-four percent of grass and sedge species were facultative wetland or obligate wetland species, while only 29% of the herbaceous species were considered wetland species. The average number of species per plot across all treatments was 9 (max 16, min 1). Species numbers were significantly ($p < 0.01$) greater on the harvest-only areas than on trenched and uncut areas, but similar to bedded areas (Figure 5). Reasons for these differences are unknown since trenched areas were considered to be more disturbed than harvest-only areas but less disturbed than bedded areas. Although these differences were statistically significant, they may not be biologically important. We believe that the difference between 10 and 8 species can not be interpreted as biologically significant. If these differences continue into the future, however, vascular species on harvest-only areas may be considered "richer" than bedded, trenched, and uncut areas. Rate of stand/successional development will have a significant effect on the continued response of vascular plants.

The low number of vascular species on the uncut area is most likely due to the heavy mat of *Sphagnum*

Long-term Implications

Overall results from this study indicate that four years after harvesting and site manipulations, jack pine seedlings responded best to bedding with N fertilization. These results, however, are dependent on the amount of soil carbon left and microsite conditions created by harvesting and site preparation.

Although jack pine production increased due to bedding and fertilization, relative cover of vascular plant groups, specifically herbaceous species, were significantly reduced due to harvesting, bedding, and trenching and did not respond to fertilization. Questions remain as to the potential changes occurring in the nonvascular plant community and in the vertebrate and invertebrate populations. Although, Meier et al. (1995) described ecological mechanisms for successional changes of herbaceous species on disturbed upland areas, development of successional and gradient/nutrient studies for mineral wetlands such as peatland studies by Dansereau and Segadas-Vianna (1952) and Bridgham et al. (1996) are needed. "New" techniques, as suggested by Ratliff and Westfall (1989) to measure quadrat changes, Stockey and Hunt (1994) to predict successional changes in wetlands, Cable et al. (1989) to assess bird-habitat quality, and Roberts and Gilliam (1995) to test theories of diversity changes on managed lands, will aid researchers and managers in monitoring changes and developing policy concerning how to manage these wetland types. Use of other silvicultural techniques, such as canopy ("green") tree retention or lengthening rotations (Franklin 1988, Swanson and Franklin 1992, North et al. 1996) while reducing the economic returns from these wetlands, may improve the overall suite of species (vascular and nonvascular), sustaining the "whole" community (Hansen et al. 1995) from cut to cut. Coarse woody debris left after harvesting will also affect water-table fluctuations and the invasion of certain vascular and non-vascular species on mineral wetlands; yet, more information is needed to determine these responses.

It is highly likely that by bedding, we are creating microsites similar to pit and mound topographies commonly found in certain northern hardwood ecosystems and in hummock and hollow peatlands (Farrish and Grigal 1985). Bedding not only creates microsites that promote wet-site *Sphagnum* mosses, bryophytes, sedges, and certain vertebrate/invertebrate populations in hollows (pits), but it also promotes tree, shrub, grass, and dry-site bryophyte species on hummocks (mounds). Species invading hummocks may be indicators of a dry-site community while those growing in hollows indicate a wet-site (Glaser 1992); yet, the community may be considered stable. Spatially, the changing proportion of wet to dry areas on a wetland will significantly influence species richness (Glaser 1992). Significantly larger "dry" areas will be created on mineral wetlands using bedding (mounding) techniques. These microsites may begin a "hummock and hollow cycle," whereby hummocks and hollows proceed successionally at different rates and therefore create a "mosaic of patches" across the wetland landscape (Watt 1947, Kershaw 1964). Successional changes on these created microsites cannot, however, be predicted at this time. Much will depend on the dynamic fluctuations of the water table in concert with climatic variables and the relative colonization of new species versus present species. Considering Grigal's (1985) estimate of *Sphagnum* growth on hummocks and hollows in raised bogs (3.6 and 9.1 cm yr^{-1}), *Sphagnum* spp. may not completely revegetate the site before the next rotation. It is highly likely that the colonization of bryophyte species in conjunction with tree crown closure will control the invasion of new vascular species.

We chose to analyze differences in vascular plants among site-preparation and fertilization treatments based on community groups that reflect general differences in environmental requirements and overall growth forms. Although we did not specifically analyze differences in individual species composition, we believe that by analyzing characteristics of woody, herbaceous, and grass/sedge species groups versus individual species, we were better able to reflect inherent and potential differences among these treatments and the original uncut area. As depicted by Brumelis and Carleton (1989), significant changes in vegetation cover could occur even after 20 yrs of revegetation on highly disturbed and high nutrient wetlands.

Continued use of these wetlands as a timber resource may *i*) decrease the rotation age of these types of forested wetlands, *ii*) completely offset long-term successional stages needed to produce the original wetland community before harvesting, creating a new wetland type on mineral wetlands, *iii*) maintain the unique species combinations as observed in this region, or *iv*) create new wetland types not yet observed in this region. These results provide a needed baseline from which to compare successional changes on these wetland types and to predict the potential wetland type after forest management. By measuring only changes in tree production on harvested sites, possible interacting effects of ground vegetation with overstory vegetation and the overall community dynamics are missed. Future research should include not only changes to vascular species but changes to non-vascular species, hydrology, nutrient dynamics, and climate effects in order to predict future changes in overall communities on these mineral wetlands.

scots pine on peat soils. Communicationes Instituti Forestalis Fenniae 1:100–110.

Paivanen, J. 1982. The effect of cutting and fertilization on the hydrology of an old forest drainage. Folia Forestalia 515.

Polglase, P.J., N.B. Comerford, and E.J. Jokela. 1992. Mineralization of nitrogen and phosphorus from soil organic matter in southern pine plantations. Soil Science Society American Journal 56:921–927.

Pritchett, W.L. and N.B. Comerford. 1982. Long-term response to phosphorus fertilization on selected Southeastern Coastal Plain soils. Soil Science Society of America Journal 46:640–644.

Ratliff, R.D. and S.E. Westfall. 1989. Monitoring plant community change: an application of quadrat classification + discriminant analysis. Vegetatio 80:1–9.

Roberts, M.R. and F.S. Gilliam. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. Ecological Applications 5:969–977.

Smith, W.B. and J.T. Hahn. 1987. Michigan's forest statistics, 1987: an inventory update. USDA Forest Service—North Central Forest Experiment Station. St. Paul, MN, USA. General Technical Report NC-112.

Stockey, A. and R. Hunt. 1994. Predicting secondary succession in wetland mesocosms on the basis of autecological information on seeds and seedlings. Journal of Applied Ecology 31:543–559.

Sutton, R.F. 1993. Mounding site preparation: a review of European and North American experience. New Forests 7:151–192.

Swanson, F.J. and J.F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. Ecological Applications 2:262–274.

Trettin, C.C., M.R. Gale, M.F. Jurgensen, and J.W. McLaughlin. 1992. Carbon storage response to harvesting and site preparation in a forested mire in northern Michigan, U.S.A. Suo 43:281–284.

Trettin, C.C. and M.F. Jurgensen. 1992. Organic matter decomposition response following disturbance in a forested wetland in northern Michigan. Proceedings of the 9th International Peat Congress 2:392–399.

Trettin, C.C., M.F. Jurgensen, M.R. Gale, and J.W. McLaughlin. 1995. Soil carbon in northern forested wetlands: impacts of silvicultural practices. p. 437–461. *In* W.W. McFee and J. M. Kelly (eds.) Carbon Forms and Functions in Forest Soils. Soil Science Society of America, Madison, WI, USA.

Trettin, C.C., M.F. Jurgensen, J.W. McLaughlin, and M.R. Gale. 1996. Effects of forest management on wetland functions in a sub-boreal swamp. p. 411–428. *In* C.C. Trettin, M.F. Jurgensen, D.F. Grigal, M.R. Gale, and J.J. Jeglum (eds.) Northern Forested Wetlands: Ecology and Management. Lewis Publishers, Boca Raton, FL, USA.

Verry E.S. 1986. Forest harvesting and water: the Lake States experience. Water Resource Bulletin 22:1039–1047.

Watt, A.S. 1947. Pattern and process in the plant community. Journal of Ecology 35:1–22.

Weetman, G.F. 1975. Ten-year growth response of black spruce to thinning and fertilization treatments. Canadian Journal of Forest Research 5:302–309.

Weetman, G.F. and R.M. Fournier. (1984a). Ten-year growth and nutrition of a straw treatment and of repeated fertilization on jack pine. Canadian Journal of Forest Research 14:416–423.

Weetman, G.F. and R.M. Fournier. (1984b). Ten-year growth results of nitrogen source and interprovincial experiments on jack pine. Canadian Journal of Forest Research 14:424–430.

Wilde, S.A. 1970. Growth potential of Wisconsin native pines on weed-invaded soils. Transactions Wisconsin Acadademy of Sciences and Arts Letter 58:197–202.

Wilde, S.A. and E.L. Zicker. 1948. Influence of the ground water table upon the distribution and growth of aspen and jack pine in central Wisconsin. University of Wisconsin, Madison, WI, USA. Technical Note No. 30.

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