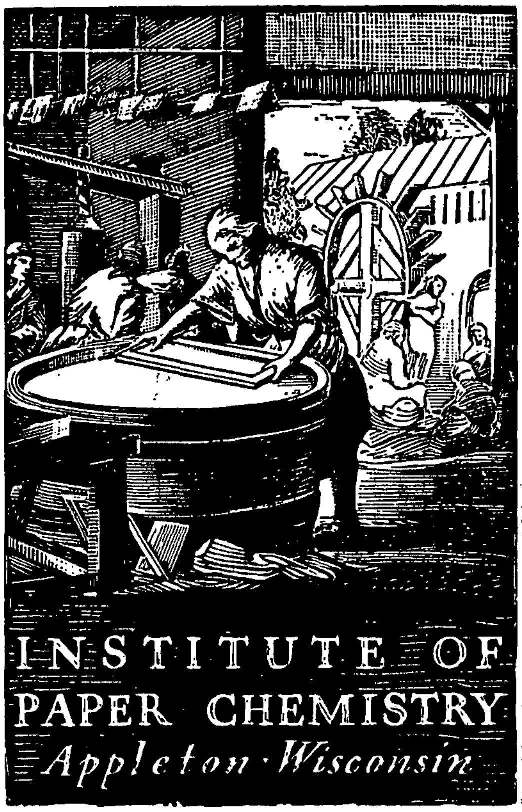


# GENETIC IMPROVEMENT OF LARCH

## Project 3409

Report One
A Progress Report
to
MEMBERS OF GROUP PROJECT 3409

March 4, 1981

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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## SUMMARY

Field observations of European and Japanese larch plantings in the Lake States and Northeast have served to generate even greater enthusiam for larch as an alternative fiber source. Despite a tight budget, activity on the project increased and progress on all phases of the program has been good. Summarized below are comments on the more important activities during 1980/81.

1. Larch selection work this past year resulted in the identification of 33 clones of European larch and 27 Japanese larch and propagation of these clones is underway. Selections included trees growing in Iowa, Michigan, Pennsylvania, and Wisconsin, along with cooperator selections (USFS, State of Pennsylvania, etc.).

2. Seed orchard plans are being developed for cooperating agencies. An eight-acre standard design has been selected that maximizes outcrossing and contains 30 clones. Three types of orchards will be available, European, Japanese and Japanese x European hybrid orchards. Variation in size can be easily accomodated to meet individual company requirements.

3. Isozyme techniques are being developed that will allow closely related individuals to be identified, thus reducing the chances of seed orchard inbreeding.

4. Established field plantings were evaluated in Iowa, Wisconsin, Michigan, and Pennsylvania to obtain an insight into early growth rate, establishment problems and insect and disease problems. Larch, it appears, will outgrow red pine on all but the very sandy, excessively drained sites.

5. Wood quality evaluation of selected Japanese and European larch trees is underway. Preliminary results indicate both species have similar age 15 fiber

lengths (2.9 mm) and comparable alcohol-benzene extractives (4.4%). European larch selections had higher specific gravity (0.43 vs. 0.38) and lower heartwood hot-water extractives (17.1 vs. 19.0%).

6. Kappa 50 and kappa 30 pulps were produced from 18-year-old European larch, 23-year-old hybrid larch and a mixture of 25% larch/75% jack pine. The larch sources gave 3-4% greater pulp yield than the jack pine. The larch/jack pine mixtures also reflected the yield advantage of larch.

7. Kappa 50 and 30 pulps were also produced using "whole-tree" chips from 8-year-old hybrid larch containing 23% bark. Pulp yields were lower by as much as 11%, compared to jack pine, and the resulting pulps were more difficult to beat, had lower tearing strength and lower ultimate breaking length.

8. The kappa 50 and bleached kappa 30 pulps of European larch and European larch/jack pine mixtures not only were produced under similar cooking conditions but developed comparable strength and drainage properties upon refining as the jack pine control pulps.

9. The bleachability of the larch pulps was similar to the jack pine control pulps, with the exception of the pulp mixture containing 25% 8-year-old hybrid larch and 75% jack pine. This pulp had higher first-stage chlorine consumption and lower final brightness.

10. Potential animal and insect and disease problems of larch were reviewed. Larch sawfly, needlecast disease and porcupine damage appear to be the external biological factors that must be evaluated and their influence minimized in larch plantings.

11. Plans for the coming year include: parent tree selection, propagation of parent trees, pulping of Japanese larch, wood quality evaluation of parent trees, isozyme studies, and establishment of two replicated field plantings.

# INTRODUCTION

The major objective underlying the establishment of the larch project is to provide the Lake States and Northeast with a rapid-growing, alternative conifer fiber supply. A second, longer-term objective is to provide a sound genetic base for additional genetic gains in growth and wood quality.

Dwight Hair (1) in an article entitled the "Timber Situation in the United States - 1952-2030" summarizes the most recent U.S. forest inventory information and emphasizes the potential seriousness of the U.S. softwood supply situation. U.S. forest service projections indicate the demand for softwood is expected to increase 82% from 10.3 billion cubic feet in 1976 to 18.7 billion cubic feet in 2030. Much of this increase is expected to take place in the 1980's. Projected demands on domestic forests for softwoods indicate an increase from 9.2 billion cubic feet (actual) in 1976 to 13.8 billion by 2000 and 15.7 billion by the 2030. Projected softwood roundwood supplies from domestic sources are expected to increase from 9.2 billion cubic feet in 1976 to 11.1 in the year 2000 and 12.3 billion by 2030.

The above cited information indicates a major imbalance between supply and demand. In a free competitive economy, such as that usually operating in the wood supply sector, prices are expected to rise to the extent necessary to bring about an equilibrium between demand and supply. Projections of softwood stumpage price changes necessary to bring about a demand-supply equilibrium indicate increases in all regions of the United States. Projected stumpage price increases* include 2.5%/year for the southern region, 1.9% for the north and northeast, 1.8% for the Douglas-fir region and 3.8%/year for the Rocky Mountain region.

[a]Price increases measured in 1967 dollars and are net inflation or deflation.

There are many social, economic and environmental implications associated with increasing prices. Cost of wood-derived products will increase, wood available for harvest will increase, removals will increase, softwood inventories will decrease, future growth could decrease, and demands for certain forest products will decrease because of high prices compared to competitive products.

A more pertinent implication to the discussion at hand is that stumpage price increases will improve the investment opportunities associated with intensive forest management. Opportunities will be improved for obtaining a reasonable rate of return from forestry operations employing genetically improved trees, fertilization and other intensive forest management practices. Dwight Hair in the latter part of his abstract summarizes the situation best: "The rise in relative prices will have substantial adverse effects on the timber processing industries, timber-based employment and income, consumers of wood products, and the environment. Such impacts are not inevitable - there are many opportunities to greatly increase and extend timber supplies, and the investments in these opportunities promise to be profitable from the standpoint of society and the economy."

# SELECTION AND PROPAGATION

## SELECTED TREES

One of the first priorities of the larch project has been to locate plantings of a suitable age for parent tree selection. Documentation of seed origin for these plantings has not always been possible although it remains an important part of the selection process whenever possible.

Many of the selection criteria developed and used during the aspen project have been readily adapted for larch selection work. Indeed, the form used for evaluating prospective aspen parent trees has been used with little modification. A copy of this form can be found in the Appendix. The major categories of data taken are heights, diameters, bark thickness, form, soil and site information, insect and disease problems, wood density, fiber length and often extractive levels. A selection index is also being developed that incorporates all of the data and allows the comparison of the parent trees through a single, numerical rating.

A large number of selections have been made of both _L. decidua_ and _L. leptolepis_. In addition, the U.S. Forest Service has allowed us access to a large number of selections in their arboretum on the Harshaw Farm near Rhinelander, Wisconsin. Cooperation has also been extended by the state of Pennsylvania and the state of New York although, at this point, selections by the latter have not been sought until assurances that the _Scleroderris_ problem in New York cannot be brought in through scion exchange. Cooperators in Europe will also be contacted for tested parent trees. Most of the European cooperators that have been exchanging _Populus_ materials with us for a number of years are also involved in larch improvement.

Table I summarizes the number and location of the various parent tree selections accumulated during the past year. A total of 33 _Larix decidua_ selections and 27 *L. leptolepis* selections have been made or obtained from other cooperators. Figures 1 and 2 illustrate the form and growth of two *L. decidua* and one *L. leptolepis* selections. Selections will continue to be made during 1981 and additional materials obtained from cooperators. A return selection trip to Pennsylvania is also planned where a number of fairly large plantings are available for both European and Japanese larch selections.

TABLE I

LARCH PARENT TREE SELECTIONS

| Parent Tree Numbers[a] | Location | Collector |
|---|---|---|
| LD-10-79 - LD-12-79 | LaCrosse, WI | IPC |
| LD-1-80 - LD-4-80 | Allamakee County, IA | IPC |
| LD-5-80 - LD-11-80 | LaCrosse, WI | IPC |
| LD-12-80 - LD-22-80 | Rhinelander, WI | USFS |
| LD-23-80 - LD-24-80 | Warren, PA | IPC |
| LD-25-80 | Cattaraugus, NY | IPC |
| LD-26-80 - LD-27-80 | Warren, PA | IPC |
| LD-28-80 - LD-30-80 | Mina Hollow, PA | IPC |
| LL-4-59, S-1 and S-2 | Clintonville, WI | IPC |
| LL-12-59, S-1 | Clintonville, WI | IPC |
| LL-1-80 - LL-8-80 | Allamakee County, IA | IPC |
| LL-9-80 - LL-10-80 | Bear Lake, MI | IPC |
| LL-11-80 - LL-15-80 | Mont Alto, PA | State of PA |
| LL-17-8 - LL-22-80 | Rhinelander, WI | USFS |
| LL-23-80 - LL-24-80 | Fulton County, PA | IPC |

[a]See Appendix for description of code; for greater detail on geographic location see Appendix Tables XXI and XXII.

Figure 1. Two 18-Year-Old European Larch Selections Growing on the Coulee Experimental Forest Near LaCrosse, WI. Both Individuals Have Excellent Form and Low Taper. Heights are Approximately 55 Feet with Diameters of Approximately 9.0 Inches bh

GRAFTING AND ROOTING

An integral part of any tree improvement program is vegetative propagation. After a prospective parent tree has been selected, it is necessary to reproduce it to meet several needs, the first of which is the preservation of the selection.

The most common method of reproduction is through grafting. This involves the joining of a detached shoot with dormant buds (scion) to a stock plant that develops into the root system of the grafted plant. There are many methods of forming the graft union but only two are being used by us with larch. However, others may be equally suitable. The primary type of graft being used is called a side-veneer graft. With this method the scion is shaped to fit a shallow cut on one side of the stock plant (understock). It is inserted into the stock so that the cambium layers match and then is tied snuggly. The second method is called a cleft graft. This is probably one of the oldest methods used. It involves cutting the top off the understock and making a vertical split down the center of the stub. A scion of the same diameter is then shaped into a wedge and inserted and tied.

Figure 2. A 19-Year-Old Japanese Larch Selection on the Yellow River State Forest. The Tree Averages 54 Feet in Total Height and 9.0 Inches dbh. Height to a Three-Inch o.b. Diameter is 35 Feet. Several Other Good Selections Have Been Made from Three Provenances

An advantage of grafting is that it allows the production of a plant that is physiologically mature; thus, it will flower and produce seed at an earlier age. This results from placing the top (scion) of a mature tree on a juvenile root system. The resulting plant maintains the maturity of the older, selected tree from which the scion was taken. However, there are problems that can develop when grafting with mature scion wood. Often, there is a period of plagiotropic growth where leader development and appearance resembles that of the top of a mature tree. Similar problems in development and form can occur if scion material is collected from too low an area in the crown (cyclophysis) or from wrong branch positions (topophysis).

Another method of propagation being used is to root cuttings taken from the parent tree selections. Juvenile larch roots quite readily but rooting ability declines rapidly with age. Several methods are being investigated to improve rooting success with older materials. One of the rooting methods used is shown in Fig. 3. A mist system is employed to provide a fine spray of water to keep greenwood (nondormant) cuttings turgid. Temperature, humidity, light quality and intensity are also controlled. Preliminary trials have shown that roots can be initiated on cuttings from older trees but with only a modest degree of success. Additional rooting work is underway this winter to investigate the feasibility of using dormant cuttings. Work in Europe with 4-year-old hybrid larch cuttings has provided an approach that appears promising.

The form problems encountered in grafting with scions from mature trees is also present in rooted cuttings from mature trees. One method that has been used for several difficult-to-root species is hedging. By repeatedly cutting back a plant and forcing a large number of shoots, it is possible to return a plant to a more juvenile state. Although losing the benefit of early flowering, the individuals propagated from these juvenile shoots will have a more normal appearance and will be easier to produce in large numbers.

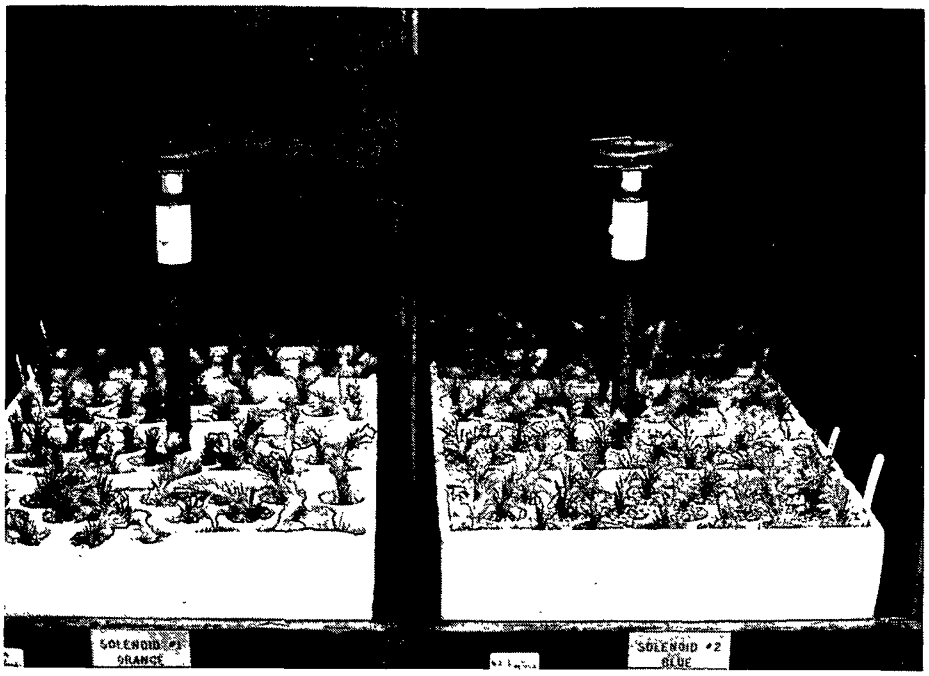


Figure 3. Shown are Two of Four Mist Chambers Being Used to Study the Effects of Different Treatments on Rooting. The Materials in this Photo are Greenwood (Nondormant) Cuttings from 20-Year-Old Larch. Other Rooting Work is Underway with Dormant Cuttings. Cutting Material from Mature Larch Roots Less Readily than Material from Juvenile Trees and Has a Longer Period of Plagiotropism

All the parent tree selections will be propagated and placed in nine-tree blocks in an arboretum now being established at the Greenville Nursery. The first blocks will be planted this coming spring with grafts made in 1979 and 1980. Problems with understock failures during last year's grafting reduced the number of clones available for planting in the arboretum. We were aware it is recommended that understock be grown in a pot for a year prior to grafting but had no stock to do so. As a consequence, we tried grafting on understock that had been potted just a few weeks earlier. Understock has been potted and grown for this spring's grafting and improved success is anticipated.

Additional rooting trials will be undertaken and the merits of hedging will be investigated. Understock will also be field planted to investigate the possibility of grafting in the field. If this approach is successful, seed orchard establishment may be hastened.

# SEED ORCHARD PLANS

## Introduction

One anticipated cooperator need is a reliable source of quality larch seed. To meet this need, it is the goal of the larch program to establish a series of first-generation seed orchards on cooperator lands as soon as possible. The approach taken has been to use a clonal seed orchard procedure similar to that used with the southern pines. Assistance to cooperating agencies is expected to take the form of: (1) selection of parent trees, (2) production of needed grafts, rooted cuttings or scions, (3) selection of seed orchard design, (4) assistance in selecting seed orchard sites, (5) assistance in laying out orchards and (6) guidance on planting techniques and methods for maintaining seed orchards.

Most of the parent trees will be selected from provenance tests and demonstration plantings in the Lake States and Northeast. The remaining parent trees will be selected trees obtained from other larch tree improvement programs (U.S. and foreign).*

## Seed Orchard Size

Genetic diversity is extremely important in seed orchard establishment. A program based upon European and Japanese larch provides the needed genetic diversity and hybrid orchards offer several interesting possibilities with even greater genetic diversity. An eight-acre seed orchard has been selected as the size that we feel appropriate for most intermediate-sized forestry operations. This is viewed as being near the minimum size for reasonable genetic diversity and seed production. The orchard size could be easily increased should an individual company so desire.

*Excellent cooperation has been obtained from the U.S. Forest Service (Rhinelander) and Lake States and Northeast state forestry organizations. Seed and scion exchange are being arranged with foreign cooperators who have been part of our aspen cooperative program.

Using a 25 x 25-foot spacing (70 trees/acre) and a 30-clone orchard (19 ramets/clone), seed production at age 18 during a good seed year is expected to be as much as 16 million viable seeds (2 million/acre). These production figures are based upon individual tree cone collections made on 18-year-old European larch plantings in the LaCrosse, WI area. European larch is estimated to have 12 seeds per cone, 2400 cones per bushel and produce about 1 bushel of cones per tree (good seed year). Individual trees have been observed that had as many as 3000 cones. Larch, unlike the pines, produces cones that take only one year to mature. This means that spring flowering and spring weather conditions can be used to estimate the fall cone crop.

## Seed Orchard Design

A number of seed orchard designs were considered and a computer generated design that maximizes outcrossing was selected as most appropriate. Figure 4 illustrates one example of the selected seed orchard design known as a permutated neighborhood design. This seed orchard approach isolates a ramet of a clone from other ramets of the same clone and also minimizes the number of times two clones are planted adjacent to each other - thus maximizing outcrossing. This computer program (2) was developed in England and, with slight modifications, can be used to mix European and Japanese larch clones to produce a hybrid seed orchard.

Presently, we are planning, as a first step, to produce nine-tree blocks of all selected parent trees. These nine-tree blocks will be a future source of scions and cuttings for vegetative propagation. The next step will be to establish company seed orchards on a first-come, first-serve basis. We feel each company should have the opportunity of establishing one orchard of about 8 acres. Then, after all companies who desire a seed orchard have their first one established, those companies wanting a second seed orchard will be accommodated. Grafted stock will be used until such time as we have worked out a satisfactory rooting procedure. A present list of seed orchard requests are as follows:

1. Consolidated - Japanese and European
2. Potlatch - hybrid
3. Scott - Japanese, European and hybrid
4. Georgia-Pacific - hybrid (scions only)
5. Mead - hybrid and European

PERMUTATED NEIGHBORHOOD DESIGN

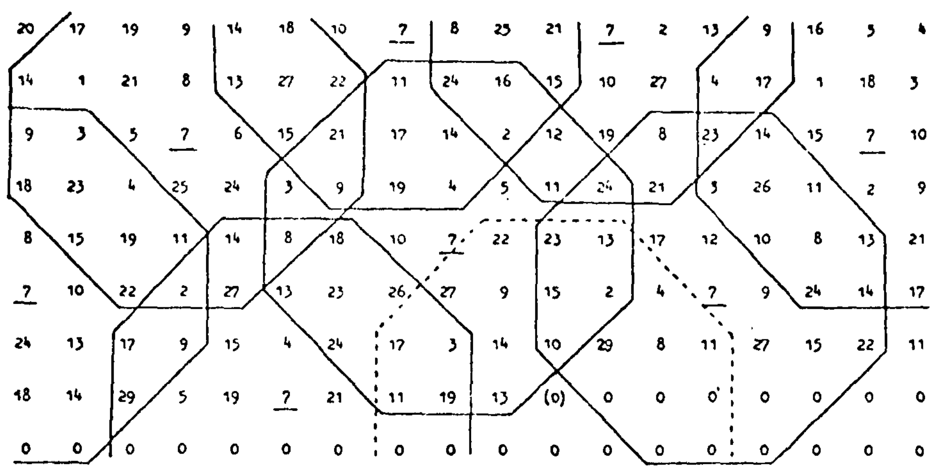



Figure 4. Example of a 29-Clone Orchard with Variable Number of Ramets Using Design Type 3 of Computer-Organized Orchard Layouts (COOL)

## ISOZYME STUDIES

Maximizing genetic diversity in a breeding population as a hedge against serious insect and disease problems and minimizing inbreeding are two important considerations when selecting parent tree clones going into seed orchards. Biochemical studies of the isozyme patterns of an individual tree are believed to be a way of determining if trees that have been selected are closely related. The seriousness of inbreeding depression (loss of growth, etc.) and the gains from hybrid vigor in larch have not been well established. Evaluation of inbreeding depression and hybrid vigor* are two logical phases of a comprehensive progeny testing program in larch.

To delay establishing seed orchards until these answers are known and progeny testing completed would be a serious mistake. One approach that can be taken in the "short term" is to assume inbreeding depression causes moderate growth losses and should be avoided whenever possible. It is normally felt that it would be undesirable to have full sibs (brothers and sisters) or half sibs (half brothers and sisters) crossing with each other in a seed orchard. Avoiding this situation is normally not a problem if good information on geographic origin of seed sources is available and there exists large numbers of seed sources to choose from. Inbreeding depression could become a problem when a number of trees are selected from the same seed source and it is not known if the seed used in establishing the stand has been collected from a single tree or a large number of widely separated trees.

Recent isozyme research with tree species has demonstrated that isozyme techniques can be used to define tree races, measure genetic variability, and determine individual tree heterozygosity (3,4). With the purpose of identifying related individuals, a student research study was initiated by Mrs. Barbara McLean. Barbara is a special Institute student and wife of a special student from Australia. The purpose of the study is to develop isozyme techniques and select enzymes that can be used to develop an isozyme profile of individual trees that will allow us to identify related individuals. Needles and greenwood shoots are being utilized and the early work has involved working out storage, extraction and electrophoretic procedures. Two enzymes, of the four to six needed for characterization, have shown considerable promise. These enzymes are cytochrome oxidase and peroxidase.

*Preliminary reports in the literature indicate that Japanese x European larch hybrids do exhibit hybrid vigor (heterosis) and improved growth rate would be one of the advantages of using hybrids.

Results

Table II and Fig. 5 illustrate some of the preliminary results obtained using cytochrome oxidase. These results suggested, for example, that, of the three European larch individuals sampled from the LaCrosse planting, trees 4 and 5 were closely related and should not be used in the same seed orchard. It should also be pointed out that L. leptolepis and the hybrid with L. leptolepis parentage has a unique band at 20 mm and the L. sibirica has a unique band at 15 mm. These conclusions are very tentative and will be reevaluated as more experience is gained with isozyme patterns.

TABLE II

POSITION OF CYTOCHROME OXIDASE ISOENZYME BANDS IN mm FROM APPLICATION SLIT, FOLLOWING SLAB GEL POLYACRYLAMIDE ELECTROPHORESIS OF DIMETHYL SULFOXIDE EXTRACTS OF LARCH NEEDLES

| Sample | Position and Intensity of Bands |
| --- | --- |
| L. decidua No. 3 | -12(±), 24(2+), 29(2+), 48(+) |
| L. decidua No. 4 | -12(+), -6(+), 24(2+), 29(3+), 38(3+), 48(2+) |
| L. decidua No. 5 | -12(+), -6(+), 24(2+), 29(3+), 38(4+), 48(+) |
| L. decidua IPC arboretum | 24(+), 29(2+), 38(4+), 48(2+) |
| L. decidua/L. leptolepis hybrid | -12(±), 20(+), 24(2+), 29(2+), 48(4+) |
| L. leptolepis | -12(±), 20(+), 24(3+), 38(2+), 48(+) |
| L. sibirica | -12(2+), 15(+), 24(5+), 38(5+), 48(+) |

Intensity Key

± doubtful

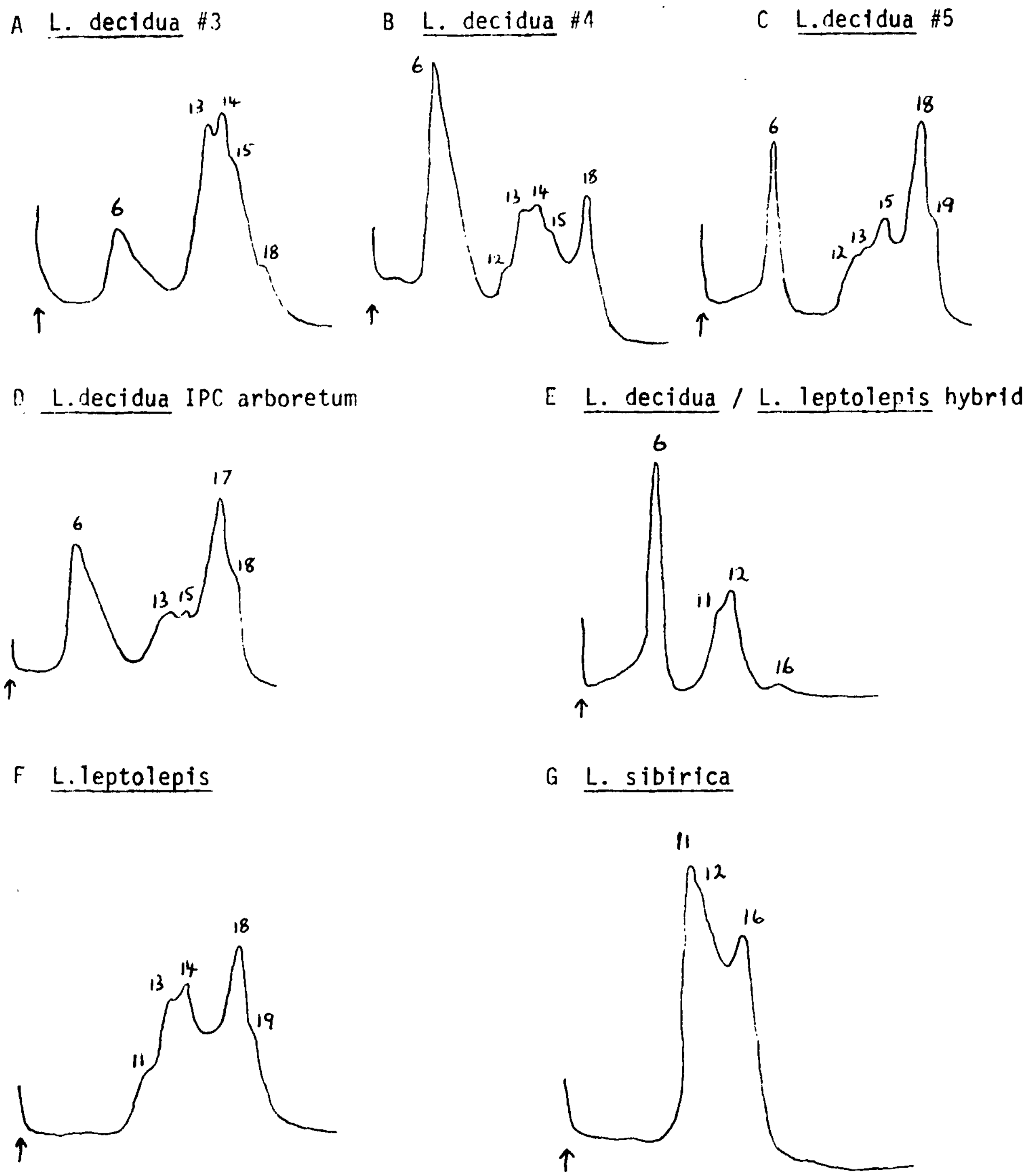
\+ weak

2+ medium

3+ medium-strong

4+ strong

5+ very strong




Numbers refer to distance in mm from top of gel. Arrows indicate top of gel. The technique of polyacrylamide disc gel electrophoresis was used to produce these results.

Figure 5. Scans of Cytochrome Oxidase Zymograms of MOPS Buffer Extracts of Larch Needles

# ESTABLISHED FIELD PLANTINGS

## LAKE STATES PLANTINGS

A number of larch plantings have been located and are being observed to gain an insight into growth and establishment problems. The majority of the plantings are near 20 years of age, reflecting a period of time when interest in larch was developing. There are also a small number of young plantings that have been established during the past two to five years. These plantings are providing information on growth and survival, site requirements, insect and disease problems, animal problems, frost tolerance, and establishment methods. The older plantings are also sources of parent tree selections. Many of the older plantings are provenance tests, which are a combination of various seed sources being tested for adaptability to a given site and geographic area. Many of these plantings are comprised of replicated blocks of small numbers of trees which do not lend themselves to volume growth measurements.

One of the first areas visited was the Yellow River State Forest in northeast Iowa. Several provenance plantings were established on the forest in 1959 by G. E. Gatherum and J. E. Kepler. Both European and Japanese larch, as well as hybrid larch, have been planted. Six-year growth data indicate that the best growth and survival occurred with two sources of Sudeten (northern Czechoslovakia) larch and the hybrid larch. The plantings do not appear to have been measured since age six. However, our measurements of parent tree selections indicate heights of 60 feet and diameters of 8-9 inches dbh on the best European larch stems at age 21.

There is also a Japanese larch planting that tests seven provenances. Eight parent tree selections have been made from this planting, all of which were within three provenances: Tochigi prefecture and two elevations in the Nagano prefecture. Selections from a fourth provenance may be added to increase genetic diversit

Growth and volume measurements are not available. However, the heights of the parent tree selections were about 55 feet with diameters of 7-9 inches dbh at 20 years.

Another area of early interest was the Coulee Experimental Forest near LaCrosse, Wisconsin. There are a number of small European larch plantings on the area, established by J. H. Stoeckler in the early 1960's as part of an erosion control research program. A total of 13 species were planted, of which the best three were European larch, white pine and red pine. The larch did so well that the then Wisconsin Conservation Department decided to produce European larch planting stock regularly in state nurseries. The early larch planting stock was produced in Ames, Iowa from Tyrolean and Styria, Austria seed sources. Selections within these seed sources will be subjected to an isozyme analysis to avoid placing closely related individuals in the same seed orchards.

Measurements of 17 larch plantings and 16 pine plantings on the Coulee Experimental Forest were taken in the fall of 1979 by the U.S. Forest Service. Ages of the plantation were 18-19 years for the larch and 19-20 years for the pine. The European larch averaged 53 feet and 6.7 inches dbh, white pine averaged 40 feet and 6.3 inches dbh, and red pine averaged 36 feet and 5.8 inches dbh. Table III gives this volume information and Fig. 6 illustrates the relative size of the European larch and red pine. Survival of the larch and white pine was approximately 60% with the red pine averaging about 85%. The plantings were originally established at rather tight spacings (6' x 6') for erosion control. Early crowding contributed to the lowered survival of the larch and white pine, which tend to have more variable growth. One larch planting had excessive mouse damage resulting in 29% survival. Plantings observed in other areas have not shown low survival. In a number of interplantings with Norway spruce, red pine, and white pine, European larch has competed well and, in the majority of these plantings, larch is the dominant species.

TABLE III

LARCH PLANTATION SURVEY
COULEE EXPERIMENTAL FOREST[a]

| Species | Age, yr | Tree/Acre, Number | DBH, inches | Height, feet | Total Volume, $ft^3$ | Growth Advantage, % |
|---|---|---|---|---|---|---|
| Larch | 19 | 558 | 6.5 | 53 | 2621 | 1.29 |
| Red pine | 19 | 823 | 5.8 | 36 | 2122 | 1.04 |
| White pine | 19 | 598 | 6.3 | 40 | 2035 | 1.00 |

[a]Values are an average of seven plots. U.S. Forest Service data.

Figure 6. An 18-Year-Old Planting of Red Pine (Left Side of Photo) and European Larch (Right Side of Photo) Growing Near LaCrosse, Wisconsin on the Coulee Experimental Forest. Larch Consistently Outgrow Red Pine on the Better Pine Sites. The Dominant and Codominant Larch Stems in this Planting Had Heights of 55-60 Feet. The Red Pine were 30-40 Feet

The Coulee area also has a number of young larch plantings from two to five years of age (Fig. 7). These plantings are of interest for both establishment and early growth information. The plantings have been established on old fields by planting in herbicide-treated strips. Early growth was minimal but comments by the area forester indicated that, once the stock is above the returning vegetation, growth accelerates markedly. A small herbicide trial is planned for this coming spring to evaluate release and establishment methods on cutover hardwood sites and possibly old fields.

Figure 7. A European Larch Planting in the Fourth Growing Season. The Trees are Growing on the Coulee Experimental Forest Near LaCrosse, Wisconsin. The Long Terminals Represent One Year's Growth and, at the Time of this Photo (July), were Still Growing. Many had 40-50 Inch Leaders by the End of the Growing Season

Two plantings that have been observed and measured periodically were established in the early stages of the Institute's genetics program when interest in polyploidy extended beyond aspen. Triploid larch had been reported and there was some concern that we might want to start working with larch. At that point, five different larch materials became available and were outplanted on the Ripco Test Area near Eagle River, Wisconsin in 1957 and 1958. A second planting was established in 1961 on the Clintonville Test Area near Clintonville, Wisconsin.

Twenty-year growth and survival data for the Ripco planting is presented in Table IV, while Fig. 8 is a view of part of the trial. Two of the sources are

Japanese larch (*L. leptolepis* and *L. dahurica*), two are European larch (*L. decidua* and *L. polonica*) and the Dunkeld source is a hybrid. The Dunkeld hybrid in this planting is actually an $F_2$ or $F_3$ generation, and, as such, is more variable than an $F_1$ generation hybrid.

TABLE IV

LARCH TRIAL I
5, 10, 15, AND 20-YEAR MEASUREMENTS
RIPCO TEST AREA

| Material[a] | 5th Year Av. Ht., feet | 5th Year Av. dbh, inch | 5th Year Survival, % | 10th Year Av. Ht., feet | 10th Year Av. dbh, inch | 10th Year Survival, % |
|---|---|---|---|---|---|---|
| Dunkeld hybrid | 11.5 | -- | 91 | 23.8 | 3.6 | 90 |
| *Larix polonica* | 11.0 | -- | 88 | 25.4 | 4.2 | 88 |
| *Larix decidua* | 7.2 | -- | 100 | 17.2 | 2.6 | 100 |
| *Larix dahurica* | 11.7 | -- | 100 | 23.4 | 4.1 | 100 |
| *Larix leptolepis* | 12.2 | -- | 100 | 24.1 | 4.1 | 100 |

| Material[a] | 15th Year Av. Ht., feet | 15th Year Av. dbh, inch | 15th Year Survival, % | 20th Year Av. Ht., feet | 20th Year Av. dbh, inch | 20th Year Survival, % |
|---|---|---|---|---|---|---|
| Dunkeld hybrid | 35.1 | 5.0 | 90 | 44.0 | 5.8 | 88 |
| *Larix polonica* | 36.8 | 5.7 | 88 | 44.9 | 7.0 | 88 |
| *Larix decidua* | 27.9 | 4.6 | 100 | 34.2 | 5.5 | 100 |
| *Larix dahurica* | 36.9 | 5.6 | 100 | 46.8 | 6.7 | 100 |
| *Larix leptolepis* | 38.6 | 5.7 | 100 | 48.4 | 6.7 | 100 |

[a]Dunkeld hybrid planted in 1957. Remaining materials planted in 1958.

Growth for most materials has slowed during the last five-year measuring interval, reflecting the close spacing at which it was planted (7 x 10 feet). Several selections were made by the U.S. Forest Service a number of years ago for inclusion in their arboretum. Two *L. leptolepis* parent tree selections were made this past fall for use in the IPC larch program. The planting will continue to be observed and measured.

Figure 8. A Twenty-Three-Year-Old Planting of Hybrid Larch on the Ripco Test Area near Eagle River, WI. At Age 20, the Planting Averaged 44 Feet in Height and 5.8 Inches dbh. Growth Slowed After 15 Years, Primarily Due to the Tight Spacing at Which it was Established, 7 feet x 10 feet

The Clintonville Larch Trial III was measured this past fall at age 20. Table V lists the seed sources used and their origin. These sources were obtained from cooperators in tree improvement programs in Europe and are different provenances than those planted elsewhere in the Lake States.

TABLE V

LARCH TRIAL III
CLINTONVILLE TEST AREA
SEED ORIGIN

| Material | Origin | Cooperator |
| --- | --- | --- |
| LS-1-59 | W. Siberia | Birger Berg, Marathon |
| LL-2-59 | Japan, Nagano Prefecture | Dr. Klaehn, Syracuse University |
| LL-4-59 | Japan, Nagano Prefecture | Dr. Klaehn, Syracuse University |
| LE-9-59 | Denmark | Bent Soegaard, Horsholm, Denmark, L. leptolepis x L. decidua |
| LL-12-59 | Japan | Shigeru Chiba, Oji Institute for Tree Improvement, Oji Paper Co. |
| LG-13-59 | Japan | Ltd. Kuriyama, Hokkaido, Japan |
| LG-15-59 | Japan | M. Iwakawa, Hokkaido Source |

Larch Trial III has shown some very interesting growth and survival on a site with a sand texture and a water table that is generally below 10 feet. Table VI gives a growth and survival summary for Trial III over a 20-year period.

The best materials are two sources of Japanese larch, LL-4-59 and LL-12-59 (from which parent tree selections for the present larch project have been made), and the one source of hybrid larch, LE-9-59. This is a very sandy, excessively drained area yet Japanese and hybrid larch appear to have reasonable potential on this site, although it is questionable whether these materials will handle a site of lower quality.

The average heights at 20 years given in Table VI show the best three materials averaging about 35 feet. There are individuals within all of these materials over 40 feet and 8 inches dbh, with one of the selected trees at 49 feet and 8.3 inches dbh. Figure 9 illustrates the form and growth of the Japanese larch material LL-12-59 from which the above mentioned larch selection was made.

TABLE VI

LARCH TRIAL III
CLINTONVILLE TEST AREA

SURVIVAL AND GROWTH SUMMARY

| Material | 5 Years Height, feet | 5 Years Survival, % | 10 Years Height, feet | 10 Years Survival, % |
|---|---|---|---|---|
| LS-1-59 | 1.4 | 71 | 3.2 | 36 |
| LL-2-59 | 4.5 | 94 | 13.3 | 77 |
| LL-4-59 | 5.9 | 83 | 16.9 | 75 |
| LE-9-59 | 4.0 | 75 | 13.4 | 67 |
| LL-12-59 | 5.7 | 90 | 17.4 | 81 |
| LG-13-59 | 4.1 | 81 | 11.7 | 56 |
| LD-14-59 | 5.7 | 94 | 16.5 | 86 |
| LG-15-59 | 3.2 | 65 | 9.7 | 29 |

| Material | 15 Years Height, feet | 15 Years DBH, inches | 15 Years Survival, % | 20 Years Height, feet | 20 Years DBH, inches | 20 Years Survival, % |
|---|---|---|---|---|---|---|
| LS-1-59 | 8.2 | 0.9 | 31 | 15.5 | 3.3 | 23 |
| LL-2-59 | 23.6 | 3.3 | 77 | 32.1 | 4.8 | 71 |
| LL-4-59 | 27.9 | 4.7 | 75 | 34.7 | 6.0 | 73 |
| LE-9-59 | 26.6 | 4.4 | 67 | 34.0 | 5.9 | 67 |
| LL-12-59 | 29.3 | 4.6 | 84 | 35.8 | 5.7 | 81 |
| LG-13-59 | 22.1 | 3.2 | 56 | 30.5 | 5.0 | 54 |
| LD-14-59 | 26.9 | 4.1 | 86 | 32.1 | 5.1 | 86 |
| LG-15-59 | 17.1 | 2.6 | 29 | 23.4 | 5.2 | 29 |

Figure 9. Shown is a 20-Year-Old Japanese Larch Material Growing near Clintonville, WI which Averages 35.8 Feet in Height and 5.7 Inches dbh

The remaining materials in the trial have not done as well as the three discussed above. One is a source of Siberian larch (LS-1-59) that has been reported as having good potential for the Lake States. Our limited experience with this species does not allow us to reach the same conclusion. The remaining materials are Japanese larch (LL-2-59) and two varieties of Japanese larch, gmelini (LG-13-59) and dahurica (LD-14-59).

One of the problems frequently brought up in association with larch is the larch sawfly. Larch Trial III has undergone two major defoliations by this insect, the most recent occurring in 1979 and a modest level of infection has been present during most growing seasons. Conditions which favor the larch sawfly have not occurred with enough frequency to have seriously affected the growth of this trial. The larch sawfly can be a serious pest if large-scale defoliation is allowed to occur repeatedly. Modest levels of defoliation can be tolerated.

The trial will continue to be observed and measured and one or two additional parent tree selections will be made.

The U.S. Forest Service has been very cooperative in providing access to both their larch selections and to data collected on their larch plantings. A USFS replicated trial near Laona, Wisconsin tests five sources of hybrid larch and one source each of European and Japanese larch and tamarack. The planting was established in 1976 on a red pine site and red pine was planted on the remainder of the area during the same year. Growth and survival data for years three and four are summarized in Table VII. The survival data is no longer valid. During the fifth growing season (this past year), considerable damage was incurred from porcupine feeding. Many stems were girdled or partially girdled near the groundline. It is doubtful if many of the severely damaged stems will survive and the form of the less damaged stems will be affected.

The best materials, prior to the porcupine damage, were two sources of hybrid larch. A number of the better stems at age four had heights of 12-14 feet. The poorest materials were the Japanese larch and the tamarack. The tamarack was planted as 2-0 stock whereas the larch materials were 3-0 stock. The Japanese larch is more prone to frost damage and there was evidence of damaged terminals this past year.

The Forest Service has decided to terminate the trial. It is hoped that they can be convinced to trap the several porcupines and continue observations and survival measurements to document what happens after severe animal damage.

TABLE VII

U.S. FOREST SERVICE
REPLICATED LARCH TRIAL
LAONA, WISCONSIN PLANTING
NICOLET NATIONAL FOREST

| Material | USFS Number | 3rd Year Height, feet | 4th Year Height, feet | 4th Year Survival, % |
|---|---|---|---|---|
| Tamarack | T7000 | 5.6 | 8.1 | 98 |
| European x Japanese hybrid | 7072 | 6.9 | 10.1 | 99 |
| Japanese larch | 7073 | 5.2 | 7.1 | 99 |
| European x Japanese hybrid | 7075 | 7.6 | 10.7 | 100 |
| European larch | 7085 | 6.2 | 8.7 | 99 |
| Japanese x European hybrid | 7250 | 6.8 | 9.0 | 99 |
| European x Japanese hybrid | 7254 | 6.6 | 9.3 | 100 |
| Japanese x European hybrid | 7377 | 6.6 | 9.2 | 99 |

Planted April 20, 1976

Tamarack was 2-0 stock

Larch was 3-0 stock

Five replications
16 tree plots
7 x 7 foot spacing?

Planted by U.S. Forest Service

All material was grown from seed at the Hugo Sauer Nursery by the Institute of Forest Genetics

Several other plantings on cooperator lands were observed this past year and parent tree selections made. A Japanese larch provenance test established on Packaging Corporation of America land near Manistee, Michigan provided two L. leptolepis selections. The planting was established in 1960 and tests eight sources of L. leptolepis and one source each of European larch and tamarack on a rather sandy, dry site. Height growth of the dominant stems is approximately 45 feet and diameters at bh average approximately 7 inches.

Other plantings visited were on Champion International lands in Menominee County, Michigan. One 20-year-old planting of European larch had excellent survival and growth but had numerous terminals damaged by porcupine at about age 15 (Fig. 10). As a result, there were a considerable number of forked tops. However, one excellent parent tree selection was made in the planting.

Figure 10. A 21-Year-Old Planting of European Larch on Champion International Lands near Norway, Michigan. Survival and Diameter Growth Have Been Good. Heights and Form Have Been Affected by Porcupine Damage that Occurred at Approximately Age 12-15. Most Stems Still Have Three to Four Good Pulpwood Sticks

Champion International also has one 14-year-old Japanese larch planting near Faithorn, Michigan and another 20-year-old European larch planting in the same area. The survival of part of the European larch planting was low and Champion International decided to thin the planting, leaving the best stems behind, to form a seed production area. The Japanese larch planting is one of the few in the northern part of the Lake States and will be observed for its growth, survival and insect problems.

An additional Japanese and European larch planting established by Blandin Paper Company, is located at Gunn Park near Grand Rapids, Minnesota. The Japanese larch in this planting has had severe sawfly defoliation for a number of years and this is affecting growth. Its location within a park limits the use of insecticides to control the problem. The European larch that surrounds the planting has been relatively unaffected.

Several tamarack plantings on Consolidated Papers land near Rhinelander, Wisconsin and on Wausau Papers lands in central Wisconsin have also been located. These plantings are of interest for future evaluation of tamarack when it becomes appropriate to consider inclusion of tamarack in the present larch program.

NORTHEAST PLANTINGS

Larch has been planted in the Northeast for a considerably longer period of time than in the Lake States. One of the oldest European larch plantings was established in 1850 in Delaware County, New York. There are also a large number of European and Japanese plantings in Pennsylvania ranging in age from 15-100 years. Although most of the older plantings are only small scattered blocks, they have been subjected to environmental pressures for a considerable period of time and have adapted well. A paper by Grisez (5) examined a large number of plantings in Pennsylvania which included both Japanese and European larch. His comments were that "in site-index values and volume growth, red pine, Japanese larch, and European larch excelled over all other species." He also stated that on the moist sites, European larch will outgrow the pine. We had an opportunity to visit Pennsylvania this past fall and observe several plantings on company lands. After viewing plantings of 1/2 to 5 acres in the Lake States, we were shown plantings of up to 100 acres The purpose of the trip was primarily to select parent trees. The selection process is quite intensive and time consuming. As a consequence, we have only started to evaluate the large number of potential parent tree sources.

The first plantings observed were European larch on Hammermill Paper Company lands in northwestern Pennsylvania. They ranged in age from 16 to 35 years with the majority around 20 years. Survival and growth have been good. Several parent tree selections were made with heights of 50-60 feet and diameters of 8-10.5 inches at approximately 20 years of age. Time did not allow us to complete all of the measurements but we were fortunate in that Hammermill has a forester with a background in genetics who has agreed to finish the measurements for us. He will also be looking for additional prospective parent trees during the normal course of his work.

Many of the plantings had a rather high degree of variability. The variability is due in part to cultural practices and to seed source. Larch has been planted at spacings used for pine establishment in virtually every planting we have seen. Comments from long-time larch growers in both Europe and the United States point to the need for wider spacing. Little or no information is available on the seed sources used. It is felt that gains in volume growth of 15-30% over that measured in present plantations could be realized by using high quality seed. Because of the lack of information on seed sources, it will be useful to examine the various parent tree selections to determine if any are closely related. To do this, an isozyme profile system will be used to more intensely characterize the parent tree selections. A discussion of this technique can be found in a previous section of the report entitled "Isozyme Studies."

Additional plantings were observed on Glatfelter Pulp Wood Company lands in south central Pennsylvania during the same trip. Again, we were impressed by the number of plantings available for selection work. Glatfelter has settled on two species for the majority of their reforestation work: Japanese larch and a pitch x loblolly pine hybrid.

The paper by Grisez cited earlier in the section pointed out that Japanese larch and European larch, when planted in mixed plantings with white pine on the same dry sites, produced different results. The Japanese larch was completely dominant over the white pine whereas European larch was represented in the upper canopy by only a few codominant trees. Our observations of Japanese larch on dry sites also indicates that it is showing better growth than first anticipated. Japanese larch has an interesting pruning habit that was first pointed out by the Glatfelter forester showing us their plantations. Apparently, Japanese larch branches are more brittle than European larch branches and the weight of snow and ice tends to strip the dead branches from the lower bole and pile them at the base of the tree. Figure 11 illustrates one of the trees pruned in this matter. Our first reaction was that perhaps the Japanese larch would be more prone to ice and wind damage but this apparently is not the situation.

Figure 11. A 17-Year-Old Japanese Larch Growing in South Central Pennsylvania. Japanese Larch Limbs are More Brittle than European Larch Limbs and Tend to Prune Under Ice and Snow Weight. Note the Pile of Branches at the Base of the Tree. Although Pruning Well in this Manner, the Trees Themselves do not Appear to be More Prone to Wind and Snow Breakage

The Japanese larch plantings we observed on Glatfelter lands ranged in age from 15-20 years. There were older plantings but time did not allow more than a cursory look at the plantings nearest our travel route. Only two parent tree selections were made. One selection was 19 years of age and was 50 feet in height and 8.1 inches dbh, the other was 17 years of age and 52 feet and 9.0 inches dbh. Seed source information was not available, although it was determined that the stock came from the state nursery at Mont Alto, Pennsylvania. This is the same nursery that provided us with Japanese larch scions from their better seed orchard selections.

Further selection work is anticipated during next year's return trip. We have been consistently struck by the number of well-established, good-appearing larch plantations we have viewed. There are occasional establishment problems but, overall, nothing has been noted that in any way detracts from our continuing enthusiasm for larch as an alternative conifer fiber source.

## REPLICATED FIELD PLANTINGS

Replicated field trials are being suggested as a way to evaluate larch performance on a variety of sites and under a variety of conditions. Several cooperators have requested trials and our intentions are to establish as many as there are requests for. Most of the plantings will be on sites that cooperators view as the kind of areas available for larch. However, we do not feel that replicated trials should be placed on problem sites as larch is not being proposed as the answer to poor quality sites. There is some preliminary evidence that larch may be able to handle poorer sites than are being suggested, but more work is needed before a large commitment is made to these areas.

The first plantings in 1981 will be established with container-grown stock. Bare root and container stock will be available for the replicated trials in 1982. The majority of the replicated plantings will be located on old-field sites and will require intensive site preparation before planting. The plantings will be testing some very highly selected seed sources, of which many are available in only small quantities. The purpose of the plantings is to evaluate performance under a fairly controlled set of conditions, not to determine minimal establishment procedures. That work will be done with more expendable seed sources. It is also being suggested that control measures be taken in areas with potentially heavy deer pressure. Fencing may be required in some instances.

The objectives of the trials are to look at growth, survival, insect and disease problems, as well as to evaluate the various seed sources. The plantings will also be potential sources of parent tree selections for use in second-generation orchards. Table VIII presents the eight sources of seed that will be used for the two plantings being put in this spring. Future trials will have several different seed sources but will also have some sources in common with those being established this spring. The intention is to tie the trials together with one or two common seed sources.

TABLE VIII

SEED SOURCES FOR 1981 REPLICATED PLANTINGS

| Material | Origin |
|---|---|
| XLD-3-79 | Northern Czechoslovakia |
| XLD-5-79 | East Germany |
| XLD-6-79 | West German seed orchard seed from selected trees within the most important natural range of European larch |
| XLL-1-79 | Japanese larch stand in West Germany - stand origin is being determined |
| XLL-2-79 | Seed orchard seed from the Penn Nursery in Centre Hall, Pennsylvania |
| XLL-5-79 | Mt. Nantai, Tochigi Prefecture, Japan |
| XLD-LL-1-79 | Seed orchard seed from the state of New York. Parent tree selections were from Japanese larch plantings in Allegheny Region of New York |
| XLTK-5-80 | Seed collected from four selected trees in Iron and Gogebic counties in Upper Michigan |

The trials will be a four-replicate, eight-material, randomized-block design with 36 trees per plot of which the 16 interior trees will be the test material and the 20 border trees will be used to eliminate edge effects. The trees will be planted at a 10-foot x 10-foot spacing. Figure 12 illustrates a typical design of a replicated planting. The actual area involved is slightly less than three acres, including a 15-foot border around the planting for tractor maneuvering.

The first two plantings (1981) will be placed on Mosinee Paper Company lands near Solon Springs, WI and on Consolidated Papers land near Rhinelander, WI.

Replicated trials will also be established in 1982 in Minnesota on Blandin Paper Company and Potlatch Corporation lands; in Upper Michigan on Mead Corporation land; and in Maine on Scott Paper Company land. Additional trials will be established in 1983 if there are requests.

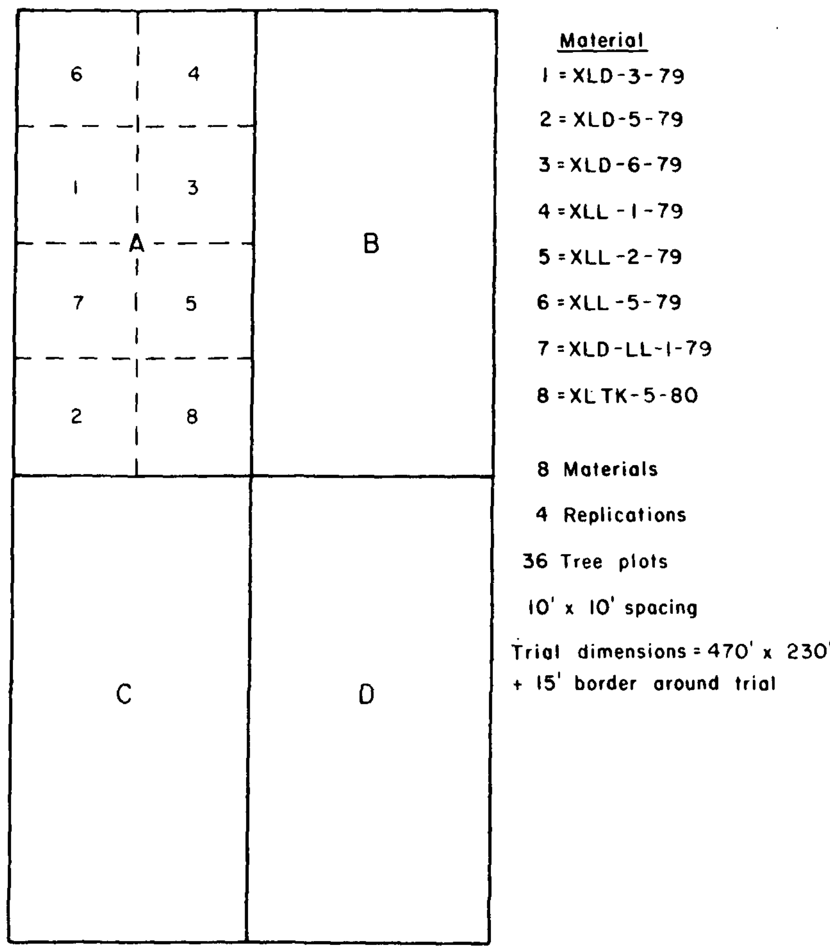



Figure 12. Illustrated is the Typical Design of a Replicated Planting

# WOOD QUALITY AND PULPING

## WOOD QUALITY OF SELECTED TREES

When the larch project was first developed, we compared the wood quality of Japanese and European larch with several other commonly pulped native species. Table IX gives some of those comparisons. Larch compared favorably with these species in terms of wood density, fiber length and alcohol-benzene extractives. Hot-water extractives of mature trees, as reported in the literature and given in Table IX, are high. However, in pulping work done at the Institute on younger trees (18-24 years old), hot-water extractives of chip samples averaged approximately 5%. Consequently, it appears hot-water extractives would not be a problem if younger-aged material was utilized.

Wood quality evaluation is an important part of any tree improvement program. To provide a base line for evaluating younger prospective parent trees, we are evaluating selected trees in terms of specific gravity, fiber length, alcohol-benzene extractives and hot-water extractives. Samples for these determinations are obtained by taking four 10-mm increment cores from each tree. In some cases, it hasn't been possible to take cores because we either couldn't receive permission to remove cores from the trees or else we received scions and didn't have access to the original tree. To date, 60 selections have been made, 33 European larch and 27 Japanese larch. Wood quality determinations have been made on 27 of these.

Specific gravity is obtained on a green volume basis on the complete core of all four cores. Rings 14-16 are then cut from two cores and specific gravity measured again, to give an age 15 specific gravity. Total core specific gravity of the Japanese larch ranged from 0.338 to 0.388 with an average of 0.374. These measurements were made on trees approximately 20 years old. When rings 14-16 were sectioned

TABLE IX

WOOD QUALITY COMPARISONS OF MATURE TREES
LITERATURE VALUES

| Characteristic | European Larch | Japanese Larch | Balsam Fir | White Spruce | Black Spruce | White Pine | Red Pine | Jack Pine |
|---|---|---|---|---|---|---|---|---|
| Wood density[a] | | | | | | | | |
| g/cc | 0.49 | 0.44 | 0.34 | 0.35 | 0.40 | 0.34 | 0.44 | 0.39 |
| lb/cu ft | [redacted] | [redacted] | 45 | 33 | 35 | 36 | [redacted] | [redacted] |
| Fiber length, mm | 3.6 | 3.6 | 3.5 | 3.3 | 3.5 | 3.0 | 3.4 | 3.5 |
| Fiber width, µm | 46 | -- | 30-40 | 25-30 | 25-30 | 25-35 | 30-40 | 28-40 |
| Alcohol-benzene extractives, % | 2.0 | 1.9 | 1.2 | 2.0 | 2.2 | 6.4 | 3.5 | 3.7 |
| Hot-water extractives, % | 7-9 | 7-9 | 3.6 | 2.5 | 2.1 | 5.0 | 4.4 | 3.0 |

[a]Expressed in terms of green volume.

from the cores, specific gravity averaged 0.378. Included in this average was one tree with a whole core specific gravity of 0.338 and a specific gravity of rings 14-16 of 0.294. This particular tree may be discarded because of its exceptionally low specific gravity and again points up the value of wood quality determinations as part of a tree's evaluation.

Total core specific gravity of the European larch averaged 0.404 with a range of 0.390 to 0.421. When rings 14-16 were sectioned from the cores, specific gravity averaged 0.432. The lower specific gravity of the young Japanese larch selections compared with the European larch is consistent with the relationships given in Table IX for older trees.

The cores that were used for specific gravity measurements were then sectioned for fiber length determinations. Rings 11-15 were removed from two cores and rings 14-16 were used from the remaining two cores. The sectioned cores were macerated and 600+ intact fibers measured for each determination. Intact fibers are measured on wood samples to give a better indication of the tree's true fiber length. This is contrasted with pulp samples where all fibers 0.3 mm and longer are measured to give an indication of actual fiber length going into the papermaking process.

Arithmetic average fiber lengths of rings 11-15 of the Japanese larch averaged 2.77 mm while rings 14-16 averaged 2.90 mm. Fiber lengths of rings 11-15 of the European larch averaged 2.82 mm, while rings 14-16 averaged 2.94 mm. Again, similar to the case for specific gravity, European larch has a slight advantage over Japanese larch in fiber length. However, fiber lengths for both species are comparable to those reported for any young, fast-growing, short-rotation conifer.

Fiber length/age curves were also completed for European, Japanese and hybrid larch. These curves showed that fiber length increases steadily from the pith outward and, in the outer rings, is comparable to fiber length obtained for mature European and Japanese larch. Table X gives the fiber length/age curve information for all three types of larch.

TABLE X

LARCH FIBER LENGTH/AGE CURVE[a]
ARITHMETIC AVERAGE

mm

| Rings | Japanese Larch | European Larch | Hybrid Larch |
|---|---|---|---|
| 0-5 | 1.50 | 1.59 | -- |
| 6-8 | 1.76 | 2.00 | 1.67 |
| 9-10 | 2.03 | 2.33 | 2.08 |
| 11-13 | 2.58 | 2.72 | 2.28 |
| 14-15 | 2.79 | 2.95 | 2.51 |
| 16-18 | 2.97 | 3.10 | 2.95 |
| 19-20 | 3.23 | | 3.25 |
| 21-23 | 3.27[b] | | 3.36 |

[a]Average based upon three trees for each type of larch.
[b]Rings 21-22 rather than 21-23.

Because of budget limitations, extractives information was not obtained on trees selected early in the project. However, since hot-water extractives, in particular, are so important in evaluating larch as a pulpwood species, we have decided to obtain both alcohol-benzene and hot-water extractives information on all future selected trees.

The procedure involves removing the first ten rings from all four cores collected for specific gravity and fiber length information and obtaining alcohol-benzene and hot-water extractives separately (not consecutively) on a composited sample of all four cores using TAPPI Standards T 204 os-76 (alcohol-benzene) and T 207 os-75 (hot-water). Given in Table XI are the first extractives values obtained. Although the values for hot-water extractives are high, they essentially represent extractives found in the heartwood, since only the first ten rings were used. If extractives had been run on the entire core, these percentages would, of course, have been reduced, since the sapwood has lesser amounts of extractives. Also, by using increment cores, the center of the tree is weighted heavier than it would be if disk or chip samples were used.

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TABLE XI

EXTRACTIVES INFORMATION[a]
SELECTED TREES

| Tree[b] | Alcohol-Benzene Extractives, % | Hot-Water Extractives, % |
|---|---|---|
| LD-23-80 | 3.6 | 16.7 |
| LD-24-80 | 7.0 | 17.6 |
| LD-30-80 | 2.5 | 16.9 |
| LL-23-80 | 5.6 | 18.9 |
| LL-24-80 | 3.3 | 19.0 |

[a]Sample used included 1st 10 rings of the composited sample of four cores for each tree.
[b]LD = Larix decidua, LL = Larix leptolepis.

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Extractives have been measured routinely on chip samples of trees cut for pulping studies and those data show much lower levels of extractives. The chip samples represent the entire bole without bark to a 4-inch top of three composited trees. Given in Table XII for comparison purposes are the values obtained on these chip samples.

TABLE XII

EXTRACTIVES INFORMATION[a]
PULPING TREES

| Species | Alcohol-Benzene Extractives, % | Hot-Water Extractives, % |
|---|---|---|
| 23-Year-old Japanese larch | 3.0 | 7.4 |
| 18-Year-old European larch | 1.8 | 3.9 |
| 23-Year-old hybrid larch | 2.5 | 4.2 |

[a]Samples used were chip samples representing the entire bole without bark to a 4-inch top of three composited trees for each species.

Based on the wood quality information given in this section, and coupled with growth rate, pulping properties, etc., larch appears to be a viable, alternative conifer fiber source. Table XIII summarizes wood quality information obtained on young Japanese, European and hybrid larch as part of this project. This information can be compared with the literature values given in Table IX for mature trees. Figure 13 illustrates a cross section of Japanese larch wood. As shown in the photo-micrograph, the latewood zone is sharply delineated and conspicuous, growth rings are distinct, and transition from earlywood to latewood is abrupt. Resin canals can also be seen.

As a further service to project cooperators, a literature search was done on the use of larch in solid wood products. A copy of the results of this search is available upon request.

TABLE XIII

WOOD QUALITY COMPARISONS
SELECTED TREES

| Property | Japanese Larch | European Larch |
|---|---|---|
| Age 15<br>Specific gravity | 0.38 | 0.43 |
| Age 15<br>Fiber length, mm[a] | 2.90 | 2.94 |
| Alcohol-benzene<br>extractives, %[b] | 4.4 | 4.4 |
| Hot-water<br>extractives, %[b] | 19.0 | 17.1 |

[a]Green volume basis.
[b]Arithmetic average of intact fibers only.
[c]Based on first ten rings of increment cores.

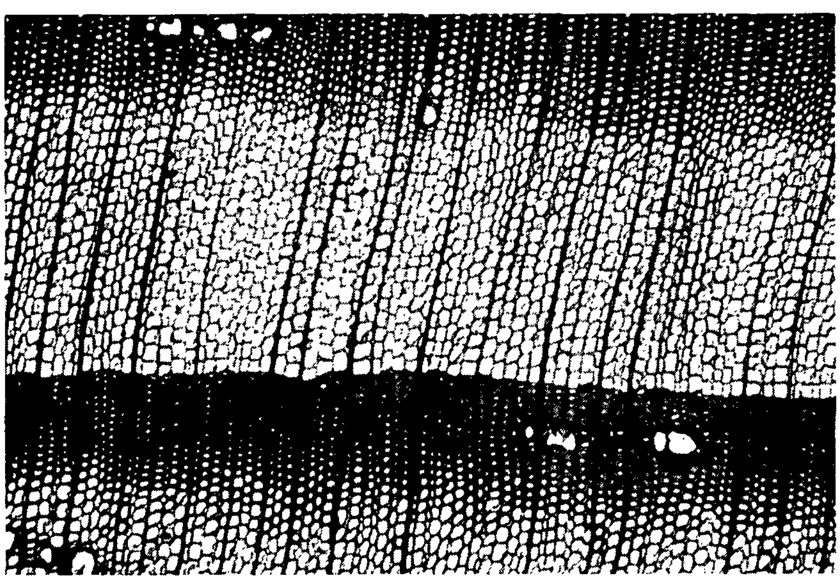

Figure 13. Cross Section of Japanese Larch Wood. As Shown in the Photomicrograph, the Latewood Zone is Sharply Delineated and Conspicuous, Growth Rings are Distinct, and Transition from Earlywood to Latewood is Abrupt. Resin Canals can Also be Seen. Magnification - 40X

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PULP PROPERTIES OF LARCH KRAFT PULPS

Introduction

Most previous investigations have examined the wood and pulping characteristics of larch of ages in excess of 50 years. Little is known about wood and pulp properties of European, Japanese and/or hybrid larch grown primarily for fiber at rotation ages of 18 to 25 years. Objectives of the larch pulping studies are to determine the usefulness of young (18-25 years) larch in the production of bag and bleachable grade papers. Four sources of larch, including 18-year-old European larch, 23-year-old hybrid larch, 8-year-old hybrid larch and 55-year-old jack pine (control), were pulped separately and in several mixtures of 75% jack pine/25% larch*.

The larch wood chips were investigated for their usefulness as bag paper by cooking to a kappa number of approximately 50 and for use as part of the furnish of bleachable grade pulps by cooking to a kappa number 30. Jack pine was used as a basis of comparison because of its common use in the Lake States and the Northeast. The mixtures selected were used because it appeared that, with the relatively limited supply of larch, the species would not be cooked alone but in mixtures with other conifers and that very likely these mixtures would contain 25% or less of larch. We presently are not advocating the use of material as small or as young as the 8-year-old hybrid larch (U.S. Forest Service), but the material does provide an extreme in wood, fiber and pulp properties that will be useful for comparison purposes.

*Age 22 Japanese larch is in the process of being pulped in a comparable manner so the results can be integrated into the study described above.

Experimental Materials

The wood chips used in the studies came from three sources of larch and a mill-run source of jack pine. Table XIV summarizes the age, tree size, percent heartwood, and percent compression wood for the four types of material used in the study. The 18-year-old European larch was from a U.S. Forest Service/Wisconsin DNR planting near LaCrosse, Wisconsin. The 23-year-old hybrid larch* was from an Institute planting near Rhinelander, Wisconsin. The 8-year-old trees were part of a U.S. Forest Service intensive management planting near Rhinelander and the jack pine was harvested in northern Wisconsin and came from the Thilmany Pulp & Paper Company woodpile at Kaukauna, Wisconsin.

TABLE XIV

TREE SIZE AND WOOD QUALITY DATA[a]

| | | | | | Breast Height, (4.5 feet) | | | |
|---|---|---|---|---|---|---|---|---|
| Type of Material | Age, yr | Height, feet | Diam., inches | Bark, % | Specific Gravity | Fiber Length, Age 15, mm | Compression-wood, % | Heart-wood, % |
| Ripco hybrid larch | 24 | 55.6 | 7.0 | 10.1 | 0.413 | 2.75 | 0.4 | 47.6 |
| European larch | 18 | 54.4 | 7.6 | 10.8 | 0.395 | 3.02 | 5.3 | 46.2 |
| U.S.F.S. hybrid larch | 8 | 21.0 | 2.0 | 18.0 | 0.370 | -- | 12.1 | 14.9 |
| Jack pine control | 55 | -- | -- | -- | 0.436 | -- | 7.5 | 28.7 |

[a]Values based on an average of three trees for the European and Ripco hybrid larch, eight trees for the U.S. Forest Service larch and eight pulpwood bolts for the jack pine.

All materials except the 8-year-old U.S. Forest Service hybrid larch were debarked, chipped and screened prior to pulping. Chips passing the 3/4-inch screen

*22-year-old Japanese larch from this same planting is presently being pulped and evaluated and will be reported on later.

and retained on the 1/2 and the 1/4-inch screens were the fractions that were pulped. The 8-year-old hybrid larch was designated as "whole-tree" chips because the material contained branches and twigs as well as the wood and bark of the main stem. Bark levels were determined to be 23%, on an oven dry basis.

Cooking and Bleaching Conditions

Pulping runs were carried out in a stainless steel vessel of about 72 liters capacity, fitted with external circulation and indirect heating. The chips were charged into a stainless steel basket, which closely matched the interior contours of the digester and which could be removed with the contents following cooking. The cooking liquors were prepared from a solution of sodium hydroxide and sodium sulfide of known concentration and density, together with the appropriate amount of dilution water. The pulping conditions employed are given in Table XV. The pulp was screened through a 0.006-inch cut screen plate in a small Valley flat screen. The rejects were oven dried, weighed and discarded. The accepted fiber was then used to determine the physical properties of the pulps using TAPPI standard methods after beating in a PFI mill at 10% consistency.

TABLE XV

PULPING CONDITIONS

| | |
|---|---|
| Constant Conditions | |
| Wood charge, kg o.d. | 4.0 |
| Water-to-wood ratio, cc/g | 4.0 |
| Effective alkali, % o.d. wood | 16.0 |
| Sulfidity, % | 25.0 |
| Time to 172°C, min | 90 |
| Cooking temperature, °C | 172 |

The kappa 30 pulps were bleached using a CEDED sequence prior to physical property evaluation. Bleaching runs were done using heat sealable polyester bags. Pulp in a crumb form was charged into the bags, diluted with deionized water and the required bleach solution added to give the appropriate bleach consistency. The bleaching conditions and chemical charges employed are shown in Table XVI. Upon completion of the bleaching time, the bag was removed, opened and the sample of pulp removed from the bleaching chemical. The pulp was thoroughly washed and returned to the bag and the remaining steps in the 5-stage bleaching sequence completed in a similar manner. Pulp from the final chlorine dioxide stage was diluted to a 1% consistency and acidified to pH 3 by bubbling $SO_2$ gas through the pulp suspension to quench any remaining chlorine dioxide activity. Brightness and handsheet strength properties were determined according to TAPPI standard methods.

TABLE XVI

BLEACHING CONDITIONS

| Bleach Stage | Bleach Chemical | Chemical Charge, % on o.d. pulp[a] | Consistency, % | Temp., °C | Time, min |
|---|---|---|---|---|---|
| 1 | Chlorine (C) | 8.3 | 3.0 | Ambient | 45 |
| 2 | NaOH (E) | 4.7 | 10 | 70 | 70 |
| 3 | Chlorine dioxide ($D_1$) | 1.5 | 10 | 60 | 180 |
| 4 | NaOH ($E_2$) | 1.0 | 10 | 60 | 60 |
| 5 | Chlorine dioxide ($D_2$) | 0.5 | 10 | 60 | 180 |
| 6 | Sulfur dioxide | 0.5 to pH 3 | 1 | Ambient | 1 |

[a]Pulp o.d. weight 500 g.

## Results and Discussion

### Introduction

Space limitations make it desirable to reduce and summarize the many observations and extensive data generated in this study. With such an abbreviated approach, some valuable data must be eliminated. As a partial solution to this problem, the decision has been made to prepare an interim Project 3409 report that would go into greater detail than is appropriate at this time. The interim report would also include results of the Japanese larch pulping work presently under way.

### Wood and Fiber Properties

In addition to the wood and fiber properties summarized in Table XIV, which were values based upon disk samples taken at 4.5 feet (breast height), fiber properties of the pulps were measured and this information is summarized in Table XVII.

The specific gravity values for the 18-year-old European larch and the 23-year-old hybrid larch were similar. The jack pine wood samples were higher in specific gravity than any of the larch samples investigated and the 8-year-old hybrid larch had the lowest specific gravity (0.37). The 8-year-old larch also had the highest level of compression wood, suggesting that, if the compression wood had not been present, the specific gravity would have been even lower.

The pulp fiber dimensions summarized in Table XVII were surprisingly similar for the several sources of larch and larch/jack pine mixtures. Fiber length of the European larch and 8-year-old hybrid larch appeared to be slightly less than the other pulps. Also, the fiber width and coarseness of this relatively young material appeared to be lower than the other pulps evaluated. Most of the values given in Table XVII are consistent with the exception of the coarseness of the hybrid larch/jack pine mixture involving the 23-year-old larch. These values were lower than anticipated and the results will be rechecked. In the samples evaluated, lower wood density was associated with the lower fiber coarseness. Also of interest was the similarity in coarseness between the jack pine control pulps and the two older sources of larch.

TABLE XVII

PULP FIBER DIMENSIONS

| Type of Material | Fiber Length, mm | | Fiber Width, µm | Cell Wall Thickness, µm | Coarseness, mg/100 m | Kappa No. |
|---|---|---|---|---|---|---|
| | Arith. | Weighted | | | | |
| Ripco hybrid | 1.7 | 2.2 | 46.7 | 5.5 | 24.6 | 53.4 |
| larch | 1.7 | 2.2 | 47.7 | 5.1 | 21.2 | 34.6 |
| European larch | 1.6 | 2.1 | 44.3 | 5.1 | 24.6 | 52.7 |
| | 1.6 | 2.0 | 45.8 | 4.7 | 17.5 | 31.4 |
| U.S.F.S. hybrid larch | 1.6 | 2.1 | 40.6 | 4.6 | 18.0 | 54.8 |
| Jack pine | 1.9 | 2.2 | 42.1 | 4.5 | 22.0 | 51.1 |
| control | 1.9 | 2.3 | 44.3 | 5.7 | 20.5 | 34.4 |
| 25% Hybrid larch/ | 1.9 | 2.3 | 40.3 | 5.3 | 15.7 | 52.2 |
| 75% jack pine | 2.1 | 2.5 | 44.2 | 5.1 | 17.6 | 31.1 |
| 25% European larch/ | 1.9 | 2.4 | 42.2 | 4.6 | 19.3 | 49.5 |
| 75% jack pine | 1.9 | 2.3 | 42.7 | 4.4 | 20.8 | 29.4 |
| 25% U.S.F.S. hybrid | 1.7 | 2.2 | 39.9 | 5.5 | 21.3 | 51.6 |
| larch/75% jack pine | 1.7 | 2.2 | 42.3 | 4.6 | 19.1 | 34.2 |

Wood Chemical Comparisons

Pulp yields are related to cooking conditions and lignin and extractive levels in the original wood samples. Table XVIII summarizes this information for the four sources of experimental chips. All sources had similar levels of lignin and the three sources of larch were similar in levels of alcohol-benzene extractives and lower than jack pine in this property. Hot-water extractives, in contrast, were higher for larch than jack pine and the 8-year-old hybrid larch had the highest level (7.4%), presumably because of the high levels of bark (23%). The lower pulp yields of the 8-year-old larch described in the section that follows reflects the

Kappa 50 Pulp Strength

Table XXIII of the Appendix summarizes the physical properties of unbleached kappa 50 pulp. Figures 15 through 18 illustrate a number of important strength property interrelationships. Figure 15 illustrates the amount of beating required to reach a given breaking length and demonstrates the differences which exist between the pulps in terms of maximum attainable breaking length. It is apparent that European larch, both alone and in the mixture with jack pine, beats at a rate similar to pure jack pine. The hybrid larch, both 8-year-old and 23-year-old, were consistently more difficult to beat and attained significantly lower maximum tensile strength. The beating characteristics and maximum breaking length values of the 25% larch/75% jack pine were similar to that of the pure jack pine, particularly for the European larch/jack pine mixture.

The 8-year-old hybrid larch was the most difficult to beat and attained the lowest maximum breaking length. The juvenile nature of the fibers and the percent compression wood are believed to be factors involved. Photomicrographs (U.S.F.S.) taken at various beating levels demonstrated that, at low beating levels, a fairly dense, well-bonded handsheet of collapsed fibers was formed and additional beating did not improve the situation. The lower zero-span tensile values (Appendix Table XXIII) suggest lower fiber strength (juvenile and compression wood) may also be involved.

Another useful way to compare pulps is to plot tear factor versus breaking length. This approach assumes the pulps are beaten to improve breaking length and, with increased beating, there will be a tearing strength loss. The better pulps are those that attain good breaking length (9-11 km) and retain tear factor values of 120 or more. Figure 16 illustrates such a comparison for the pulps involved in this study. The 8-year-old hybrid larch and the mixture of this hybrid and jack pine had lower strength values, while the 23-year-old hybrid larch, the 18-year-old European larch and the 25% larch/75% jack pine mixtures appeared to be comparable and had better tear/breaking length strength properties than pulps containing the 8-year-old "whole tree" pulps.

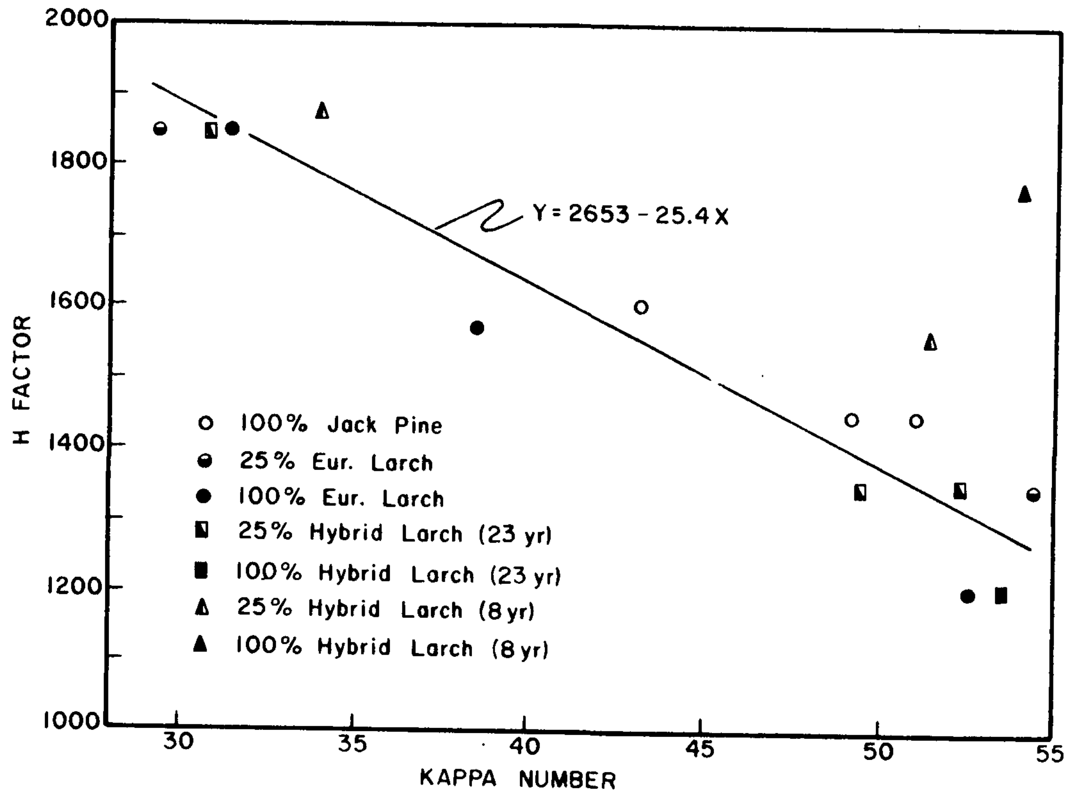


Figure 14. H-Factor Requirements vs. Kappa Number

Plotting burst factor vs. breaking length (Fig. 17) and apparent density vs. breaking length (Fig. 18) indicated that the pulps behaved in a manner typical of most conifers and that there were no important differences between the pulps evaluated.

Kappa 30 Bleaching Results

Literature describing pulping of older-aged larch often described bleaching problems. The bleaching characteristics of the kappa 30 pulp were investigated using the previously described bleaching procedure. Table XX describes the use of a CEDED bleaching sequence. The bleached pulps produced were then evaluated for strength

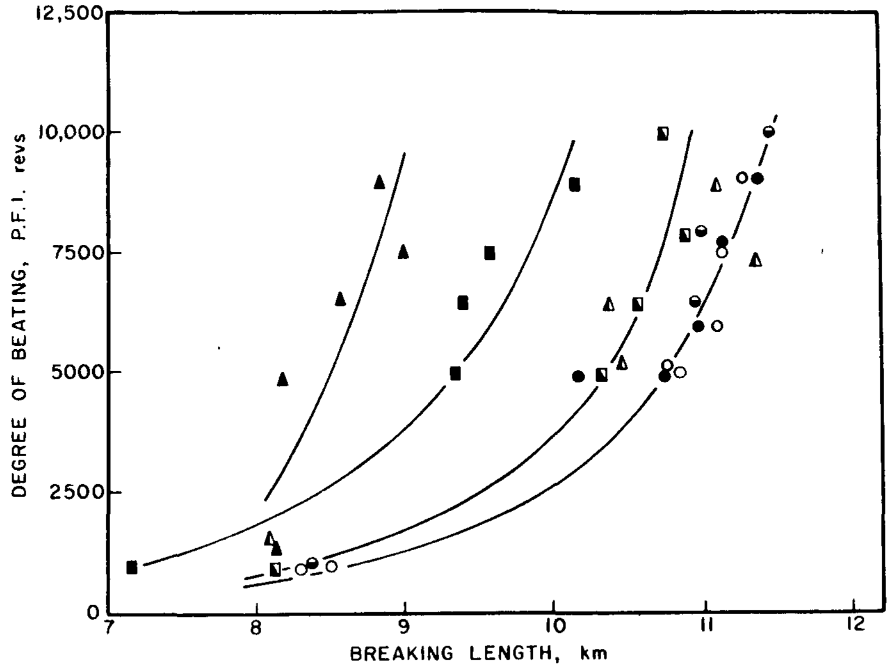


Figure 15. Degree of Beating Required vs. Breaking Length, Kappa 50 Pulps

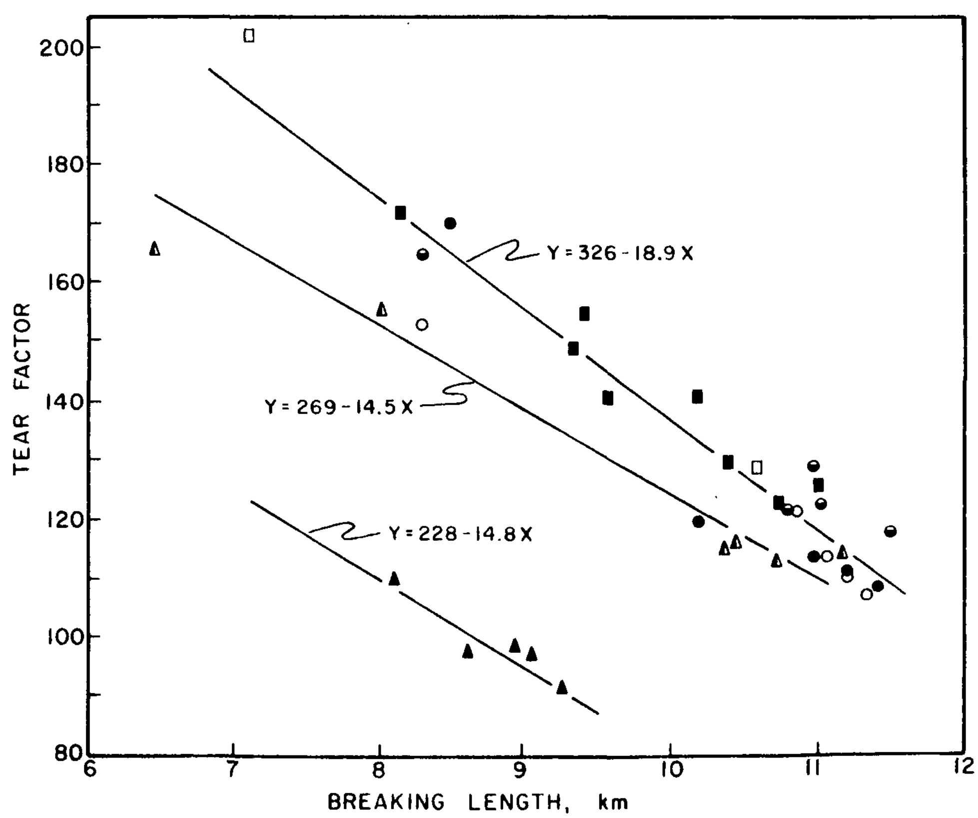


Figure 16. Tear Factor vs. Breaking Length, Kappa 50 Pulps

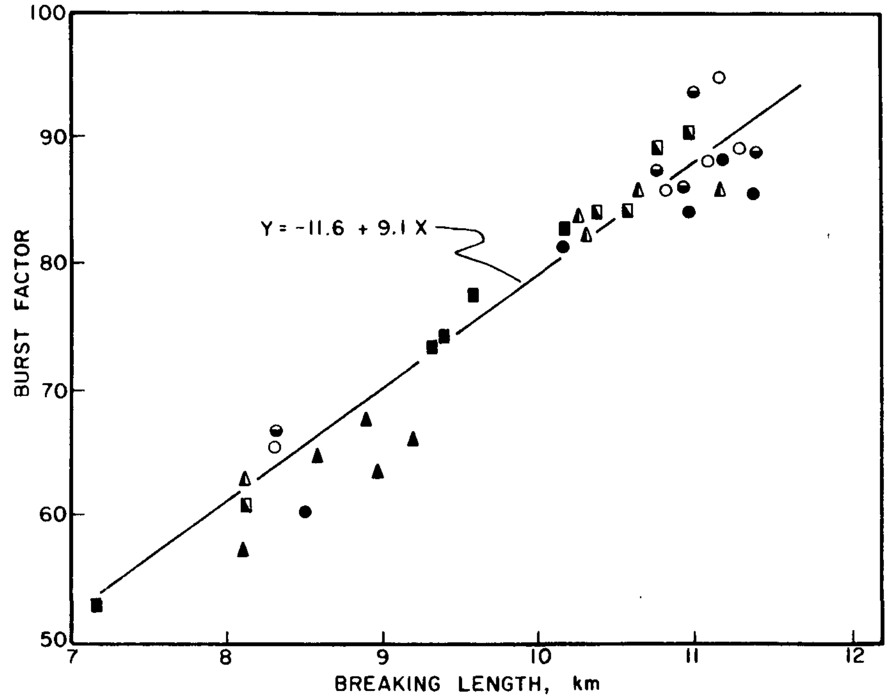


Figure 17. Burst Factor vs. Breaking Length, Kappa 50 Pulps

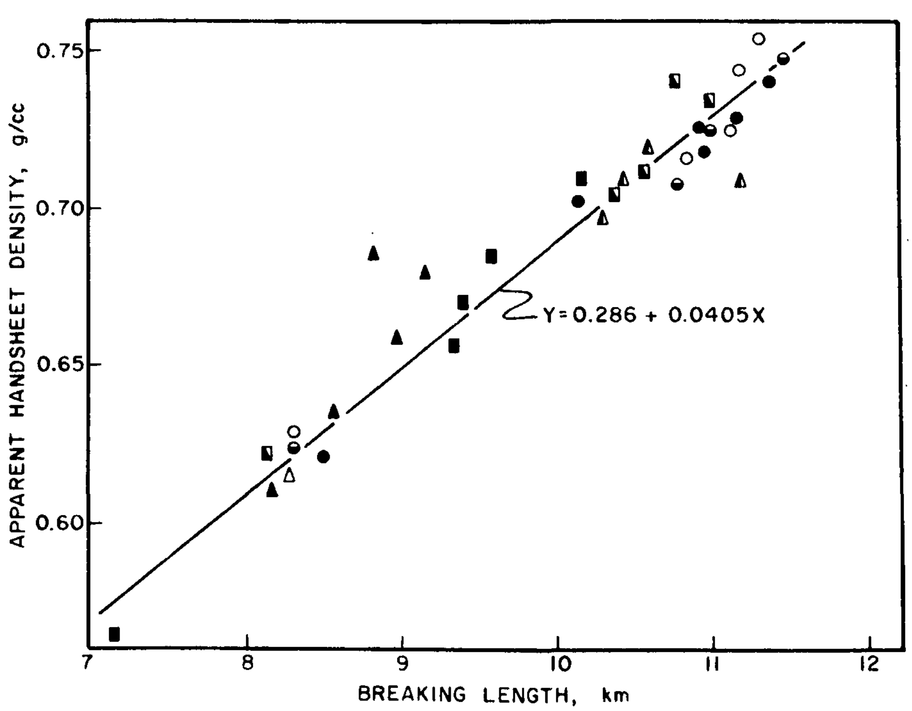


Figure 18. Apparent Handsheet Density vs. Breaking Length, Kappa 50 Pulps

TABLE XX

BLEACHING RESULTS OF 30 KAPPA PULPS

| Wood Type | Chlorination Stage ($C_1$) % $Cl_2$ Consumed on o.d. pulp | Extraction Stage ($E_1$) Permanganage No. (25 mL) | Extraction Stage ($E_1$) End pH | Chlorine Dioxide Stage ($D_1$) % $ClO_2$ Consumed on o.d. Pulp | Extraction Stage ($E_2$) End pH | Chlorine Dioxide Stage ($O_2$) % $ClO_2$ Consumed on o.d. Pulp | G.E. Brightness, % |
|---|---|---|---|---|---|---|---|
| 100% Jack pine | 7.0 | 5.2 | 12.0 | 1.20 | 10.5 | 0.4 | 90.3 |
| 100% European larch | 7.3 | 5.3 | 12.2 | 1.44 | 10.9 | 0.4 | 88.2 |
| 100% Hybrid (23) larch | 7.0 | 5.7 | 12.2 | 1.32 | 11.3 | 0.21 | 88.3 |
| 75% Jack pine + 25% European larch | 7.2 | 4.9 | 12.3 | 1.28 | 10.8 | 0.25 | 89.5 |
| 75% Jack pine + 25% hybrid (23) larch | 7.0 | 4.6 | 12.7 | 1.27 | 10.4 | 0.23 | 90.2 |
| 75% Jack pine + 25% hybrid (8) larch | 8.3 | 5.9 | 12.4 | 1.38 | 12.3 | 0.20 | 84.6 |

properties. The pulps from the two older sources of larch and the pulp from mixtures of the older larch with jack pine attained appropriate brightness levels and had similar chemical consumption as the jack pine control pulp. The pulp mixture of the 25% 8-year-old larch/75% jack pine had higher first-stage chlorine consumption and a lower final brightness.

Kappa 30 Pulp Strength Properties

The kappa 30 bleached pulps were evaluated using procedures similar to those used for the kappa 50 pulps. Appendix Table XXIV summarizes these evaluations. The kappa 30 pulp reacted to beating in a similar manner and developed similar strength as the kappa 50 pulps. Figure 19 illustrates the breaking length beating requirements. The European larch and jack pine behaved, as with the kappa 50 pulps, in a very similar manner. The 23-year-old hybrid and the two 25% hybrid larch/75% jack pine mixtures also reacted to beating in a manner similar to the jack pine bleached pulp. This appears to have occurred because, as the result of cooking to kappa 30 and bleaching, additional lignin was removed.

Removing greater amounts of lignin reduced inherent differences between fiber sources and, as a result, they reacted to refining in much the same way. Figures 20 through 22 confirm that the bleached kappa 30 pulps tended to respond to refining in a similar manner. Scattering coefficient measurements are related to bonding (lower values equal greater bonding). Figure 23 compares the response of the several pulps in terms of scattering coefficients <u>versus</u> beating and further substantiates the similar nature of the kappa 30 bleached pulps.

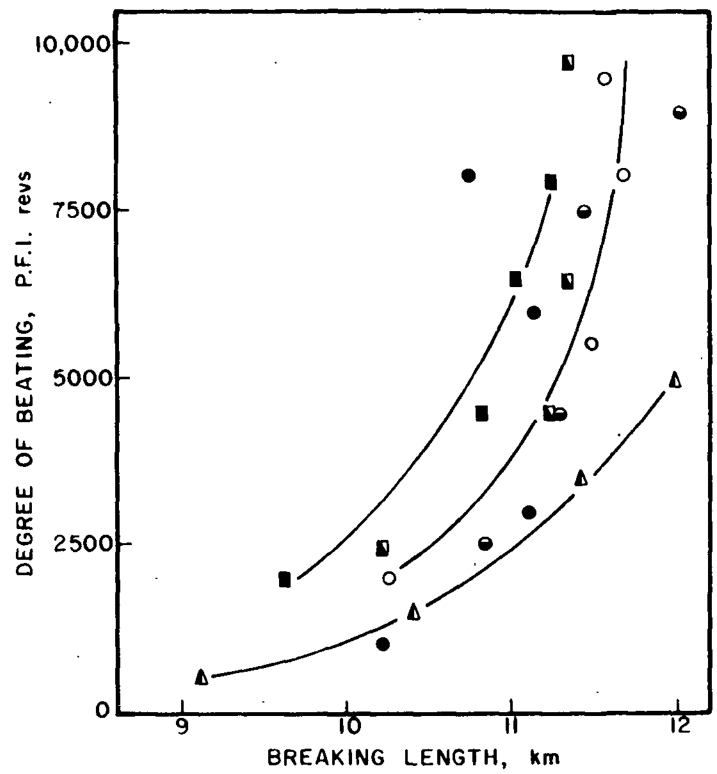


Figure 19. Degree of Beating Required vs. Breaking Length, Kappa 30 Bleached Pulps

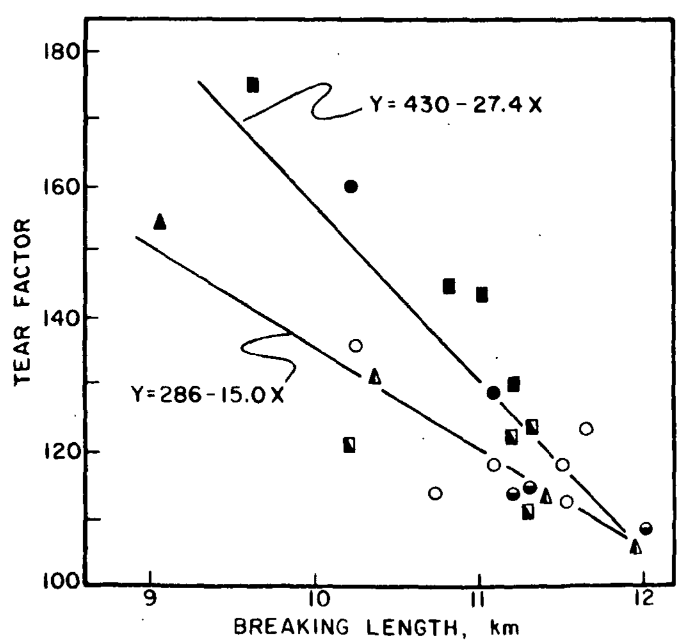


Figure 20. Tear Factor vs. Breaking Length, Kappa 30 Bleached Pulps

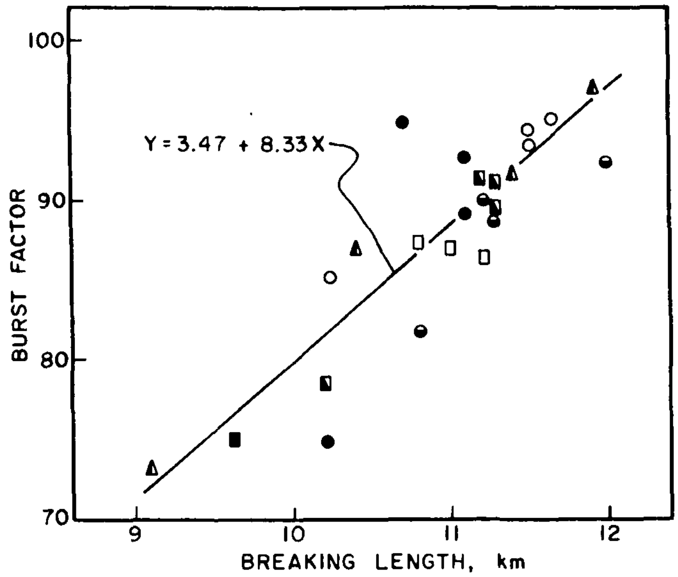


Figure 21. Burst Factor vs. Breaking Length, Kappa 30 Bleached Pulps

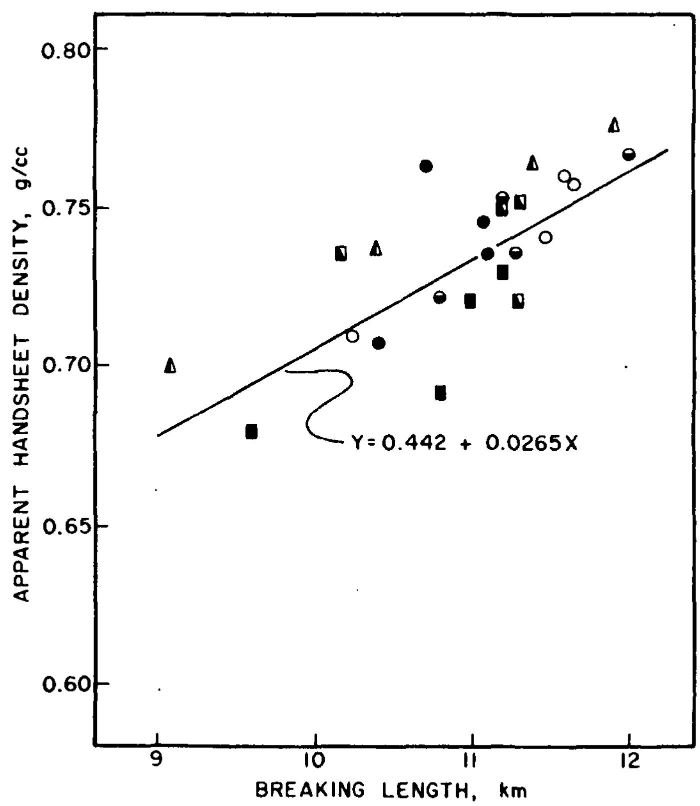


Figure 22. Apparent Handsheet Density vs. Breaking Length, Kappa 30 Bleached Pulps

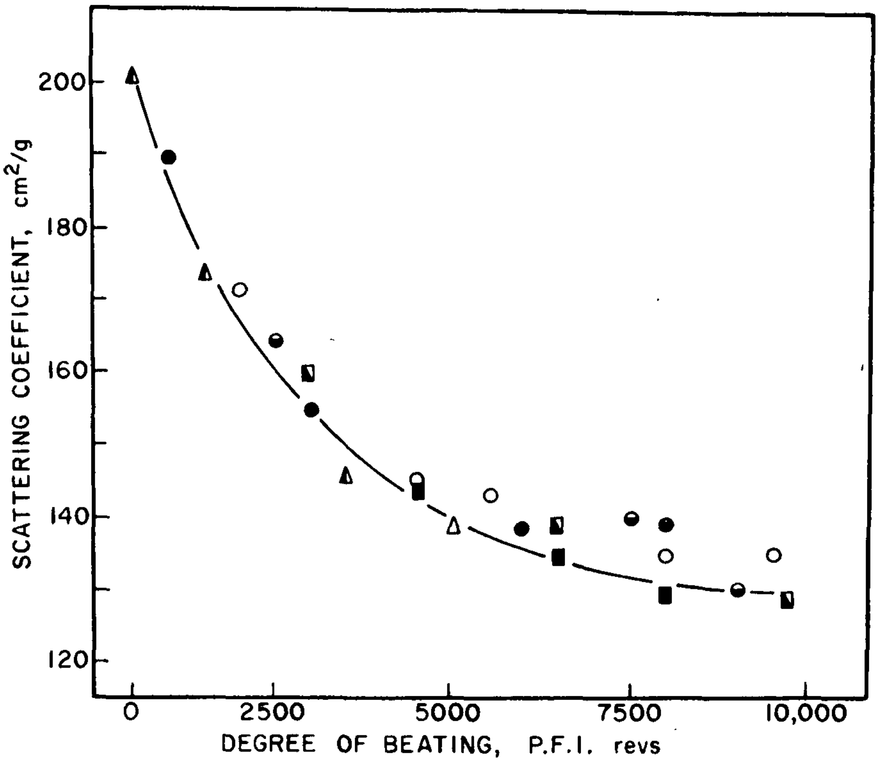


Figure 23. Scattering Coefficient vs. Degree of Beating

Strength Properties of Kappa 30 Bleached Pulp/Hardwood Pulp Mixtures

To evaluate the relative usefulness of the bleached kappa 30 pulps in improving the properties of bleached hardwood pulps, the following mixtures were prepared and evaluated:

| Symbols | |
|---|---|
| O | 50% bleached jack pine + 50% bleached hardwood pulp |
| □ | 50% bleached European larch + 50% bleached hardwood pulp |
| △ | 50% bleached hybrid larch (23 yr) + 50% bleached hardwood pulp |
| ■ | 50% bleached jack pine/European larch mixture + 50% bleached hardwood pulp |
| ▲ | 50% bleached jack pine/hybrid larch (23 yr) mixture + 50% bleached hardwood pulp |
| X | 50% bleached jack pine/hybrid larch (8 yr) mixture + 50% bleached hardwood pulp |

Appendix Table XXV summarizes the results of these comparisons and Fig. 24 through 27 illustrate the reaction of these pulp mixtures in terms of strength properties and bonding (scattering coefficients) to refining. All of the bleached conifer/bleached hardwood mixtures responded in a similar manner with the exception of the mixture containing the 8-year-old hybrid larch pulp. This pulp was better bonded than the other pulps (when compared at comparable levels of beating and/or handsheet density) but had lower tearing strength at comparable breaking length levels.

Summary

Kappa 50 pulps for use as bag papers and kappa 30 pulps for bleached grade pulps were produced by pulping European larch, two sources of hybrid larch and jack pine control chips along with several 25% larch/75% jack pine mixtures. Standard TAPPI methods were used in evaluating the pulps. The results are summarized as follows:

1. The larch chip sources and the mixtures with jack pine cooked at similar or slightly faster rates than jack pine.
2. Unscreened yields, except for the 8-year-old, whole-tree chips, were 3-4% higher for larch than jack pine. Pulp yields of the larch/jack pine mixtures reflected the presence of larch in the mixtures.
3. Unscreened yields of kappa 50 pulps from the 8-year-old hybrid larch whole-tree chips were about 11% lower than the bark-free jack pine chips.
4. Cooking larch chips to kappa number 50 resulted in large quantities of screen rejects that were eliminated by cooking to kappa number 30.

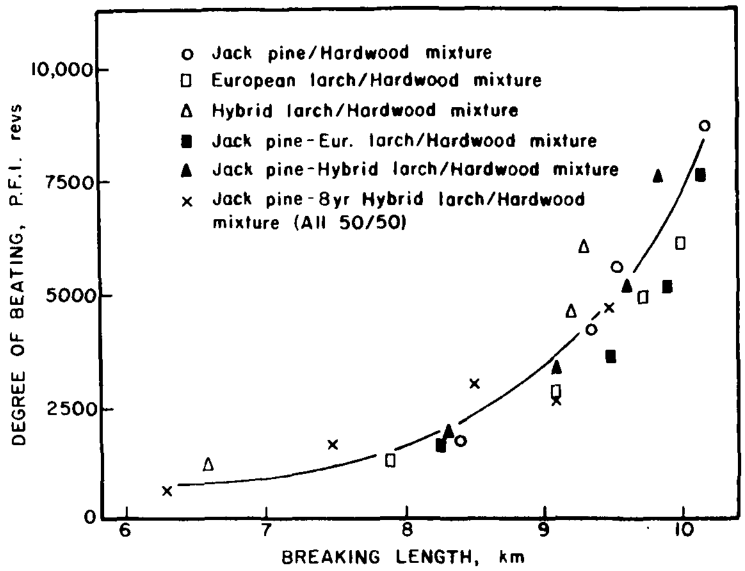


Figure 24. Degree of Beating vs. Breaking Length, Bleached Conifer/Bleached Hardwood Pulp Mixtures

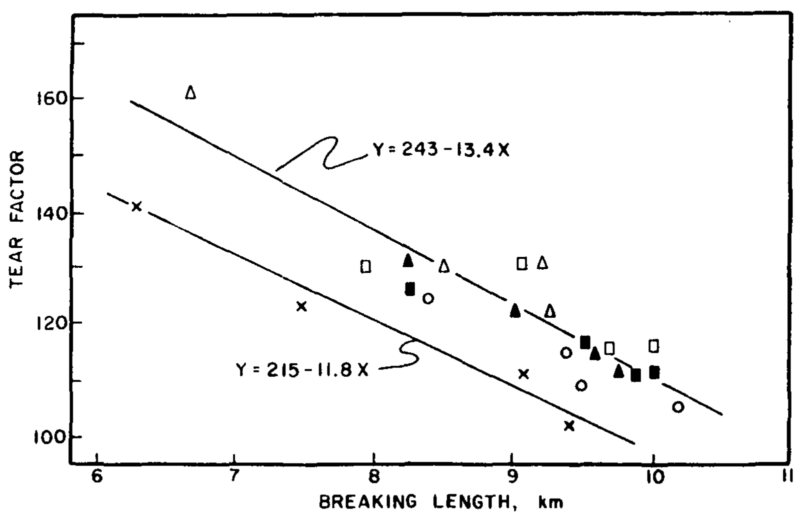


Figure 25. Tear Factor vs. Breaking Length, Bleached Conifer/Bleached Hardwood Pulp Mixtures

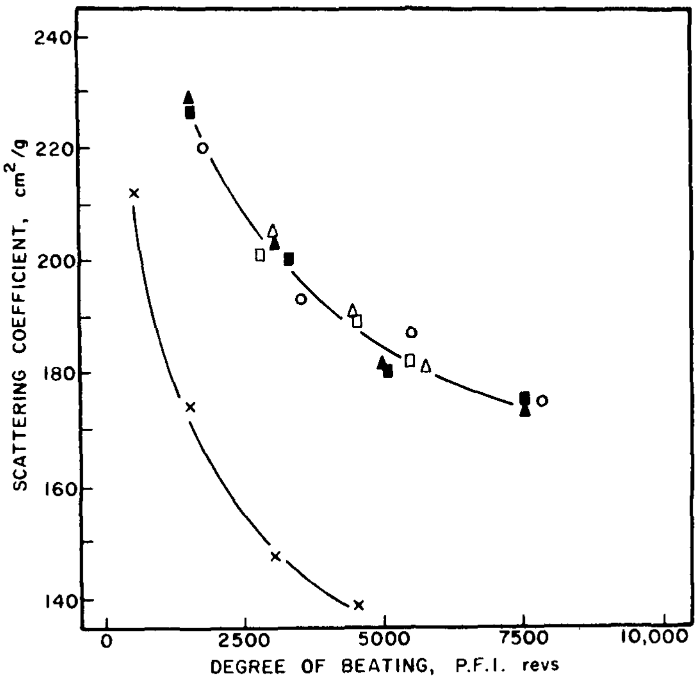


Figure 26. Scattering Coefficient vs. Degree of Beating, Bleached Conifer/Bleached Hardwood Pulp Mixtures

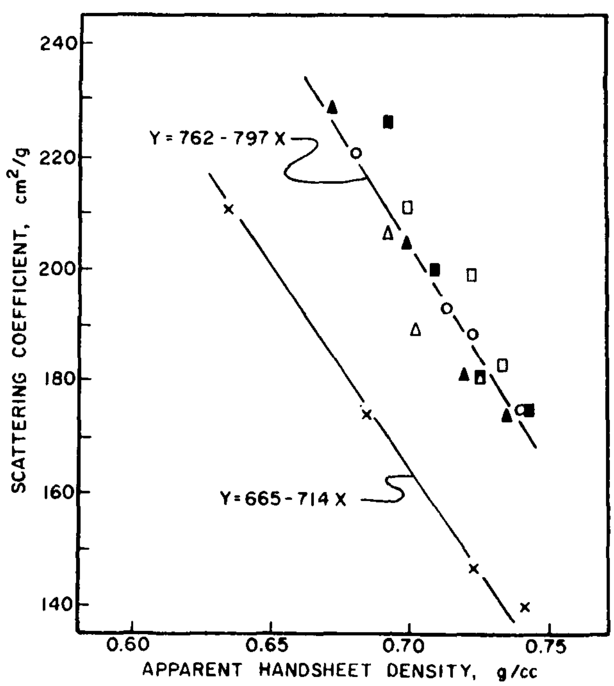


Figure 27. Scattering Coefficient vs. Apparent Handsheet Density, Bleached Conifer/Bleached Hardwood Pulp Mixtures

5. The kappa 50 pulps of the 23-year-old hybrid larch and the 8-year-old hybrid larch were more difficult to beat and developed lower ultimate breaking length than the European larch, jack pine and the 25% larch/75% jack pine mixtures.
6. The kappa 50 pulps from the 8-year-old hybrid larch and the mixtures with jack pine had lower tear and the lowest ultimate tensile strength. Tearing strength of the European larch and the 23-year-old hybrid larch was slightly higher than jack pine at the same breaking length.
7. The bleachability of the larch pulps was similar to the jack pine control pulps, with the exception of the pulp mixtures involving the 8-year-old hybrid larch and jack pine, which was more difficult to bleach.
8. Pulping larch and larch/jack pine mixtures to a kappa 30 followed by bleaching resulted in pulps that had strength properties that were very similar to the jack pine control. Only the 8-year-old hybrid larch/jack pine mixture had lower tear as the result of refining to develop breaking length.
9. When bleached larch and bleached larch/jack pine pulps were mixed with bleached hardwood pulps, the strength properties were comparable to the strength of pulps prepared from bleached jack pine/bleached hardwood pulp mixtures. The only exception was the bleached 8-year-old hybrid larch-jack pine/bleached hardwood pulp mixture. This mixture had lower scattering coefficient and lower tear than the other pulp mixture.

# INSECT, DISEASE AND ANIMAL DAMAGE

## INSECT PROBLEMS IN LARCH

A list of insect pests attacking any given species, without qualification, would be sufficient to eliminate that species from a reforestation program. The following discussion of insect pests of larch should be reviewed with the understanding that larch is relatively free of major insect problems, the exception being the larch sawfly and, to a lesser extent, the larch casebearer. A discussion of these two will be presented but other pests will only be mentioned for the sake of awareness.

The larch sawfly, Pristiphora erichsonii Htg. is assumed to be an introduced species, arriving in eastern North America around 1880. Heavy defoliation of tamarack stands in the Lake States occurred in the early 1900's and outbreaks have occurred several times since then.

Larch sawfly adults have a prolonged period of emergence, extending from about the middle of May into August (a factor that should be considered when control measures are undertaken). Sawfly eggs are placed in a series of slits cut into the underside of a new shoot by the female's ovipositor. The incubation period for the eggs last about 7-10 days. After hatching (Fig. 28) the larvae feed in colonies, moving down a branch as they consume the needles. When the larvae reach full development, they drop from the tree and burrow into the duff until they find favorable moisture conditions. On upland sites this is usually the upper portion of the mineral soil. In swamps the larvae do not go deeper than a few inches. After reaching a favorable site, the larvae form cocoons and remain there for about ten months, although some may remain for 2-3 winters. The pupae develop within the cocoons from late spring to midsummer and adults emerge after 7-10 days and the life cycle begins again.

Figure 28. The Larch Sawfly Can be A Serious Defoliator of Larch. At the Tip of the Knife Point are a Number of Newly Hatched Sawfly Larvae that are Beginning to Move Down the Branch as they Feed. Not Well Illustrated is the Location of a Current Oviposition Site on the Newly Developing Shoot. Major, Recurring Sawfly Outbreaks can be Controlled

A number of factors influence sawfly population mortality. Excessive heat, rodent populations, drought, excessively wet conditions, tree vigor, and parasites are major causes of mortality. Sawfly outbreaks appear to be associated with favorable environmental conditions. Extreme drought or high precipitation are reported by Graham (6) to be unfavorable for sawfly survival.

A modest amount of defoliation can be tolerated. It is only when insect populations reach extreme levels that control measures need to be undertaken. A paper by Hanson (7) indicated that sawfly infestations can be controlled effectively with two aerial applications of Malathion. A second application is needed because of the prolonged emergence of the adults. A spray program would not be an annual necessity; rather, it would be applied only when outbreaks are severe. Methods of determining potential outbreak situations are available.

Another potential serious defoliator of larch is the larch casebearer, an introduced moth species that was first recorded in North America in Massachusetts in 1886. It now occurs throughout the range of tamarack and has become a problem with western larch. Outbreaks have occurred at about eight-year intervals in eastern Canada and one outbreak was recorded in the Lake States in the late 40's and early 50's.

Eggs are deposited in early summer and hatch in about two weeks. Larvae bore into needles and mine them until late summer. A single larvae may mine several needles. A larva lines a hollowed section of the needle with silk and chews the section free at both ends, forming a case. During fall, the larvae migrate to an outer twig and fasten their cases to the base of buds. The most serious damage is done by the large larvae feeding on new foliage in the spring. Unlike the sawfly, the casebearer adults have only one generation per year.

The larch casebearer was the subject of a parasite introduction program in the 1930's. Two of the five species released became established and casebearer populations dropped considerably. Populations have generally remained low enough to cause little concern. The control of the larch casebearer by parasites is a successful example of biological control. The parasites have been collected in northern Wisconsin. Malathion has been shown to be an effective insecticide in controlling the casebearer as well as the larch sawfly.

There are a number of minor insect pests that do attack larch. However, the majority require a tree of low vigor for successful infestation. Larch serves as a primary host for relatively few insects. A brief discussion of the various insects that may be encountered on larch follows.

There are several other lepidopterous larvae that are defoliators of tamarack but they are of minor consequence. Tamarack is occasionally attacked by a number of wood borers such as the white-spotted sawyer, balsam fir bark beetle, spruce timber beetle, horntails, flatheaded fir borer, cedar tree borer, all of which are associated with low-vigor or dead trees. All have other primary hosts.

Larch also have bud and cone pests that would be of significance in a seed orchard. Among them are Megastigmus laricis (chalcid-flies), spruce coneworm (preferred hosts are white spruce and balsam fir), and the spruce budworm which attacks tamarack if it is among the preferred species.

The Pale's weevil, a root borer, occasionally attacks larch. Of greater concern are white grubs (larvae of Phyllophaga spp.), particularly in fields that have been under sod for more than two years. This insect could become destructive in plantations on old fields, primarily by reducing vigor.

Tamarack has a number of bark borers and phloem feeders, of which the major pest is the eastern larch beetle. It is not considered to be important economically and prefers dying or injured trees. There are about 30 species of flatheaded borers attacking conifers of all kinds, but most are generally local pests and again prefer weakened or dead trees.

There are also a number of sucking insects such as spittlebugs, aphids, spider mites and adelgids that occur on tamarack and larch but are not serious other than a local infestation.

The larch sawfly and, to a lesser extent, the larch casebearer are the two most serious insect pests that need to be considered. Control measures are available for both and, coupled with plantation observations, serious damage can be avoided.

DISEASE PROBLEMS OF LARCH

Information on disease problems with larch in the United States is rather limited. Much of the information presented relates to tamarack with the assumption that similarities in susceptibility exist. Tamarack is a host for a number of pathogens but none are serious enought to have an impact. Information on European, Japanese and hybrid larch diseases in the United States has pointed to some areas of concern but nothing seriously affecting larch has been found. The following discussion will center on diseases of tamarack and problems in Europe and Japan, as well as scattered larch plantings in the United States.

Several species of Melampsora, a rust, are found on larch. Larch and about twenty other species of conifers serve as alternate hosts for rust (8). Some premature shedding of needles accompanies the needle rusts but, with the larches being deciduous, the impact is negligible. The rust has its greatest impact on cottonwood-type materials and plantations of larch and cottonwood should be isolated from each other.

Other foliage problems with Japanese larch have been reported in Japan, the major one being the needlecast disease, Mycosphaerella larici-leptolepis. The needlecast disease, Cladosporium spp., is also present in Europe on Larix and Picea spp. but has not been reported in North America. A needlecast problem has developed in a specific European larch provenance on the Yellow River State Forest in Iowa and on two small plantings of European larch on the Coulee Experimental Forest near LaCrosse, Wisconsin. The pathologists studying the disease feel it is site related and, although concerned, do not feel it is a major problem.

Branch and bole cankers caused by Dasyscypha willkommii were reported on both European and Japanese larch in Massachusetts in 1927 (9). It produces destructive trunk and branch cankers and is prevalent in larch plantations in lowlands of western

Europe. The principal damage to larch plantations is caused by the distortion and weakening of cankered branches and boles, predisposing them to wind and snow breakage. Control of the disease in Europe is a silvicultural problem. Larch on favorable sites not subject to recurring frost damage maintain vigor and are not seriously injured. A resurvey of the larch canker problem in Massachusetts taken in 1965 after eradication attempts found no evidence of the disease and it is believed the disease is no longer a problem (10).

Another larch canker, Leucostoma kunzei, has been reported in Quebec, Canada (11). Individual cankers develop slowly but, when numerous, their combined actions may girdle and kill trees. Canker development was associated with drought and, under more favorable conditions, larch trees healed over the cankers.

The Scleroderris canker problem (Scleroderris lagerbergii) that is developing in the Northeast and is serious on the hard pines will have little to no impact on larch. Larch is one of the species attacked but sustains little damage. The greatest concern regarding larch and Scleroderris is the ability of larch to be a carrier. For that reason, no attempt to bring in scions or planting stock from the Northeast is anticipated in the near future.

There are several root rots that have been reported on larch, of which Armillariella mellea (formerly Armillaria mellea) is the primary concern. This fungus is a soil-borne saprophyte but can become a primary pathogen on a wide variety of plants. Trees are killed when the cambium of roots and lower bole are destroyed. Plantings on cutover oak sites appear to have the greatest risks.

A paper by Singh and Richardson (12) suggests that the incidence of Armillariella root rot varied considerably between species and modes of establishment. Of the fifteen species evaluated, L. leptolepis had one of the lowest infection rates. Container stock had no incidence of Armillariella and bareroot stock had the highest incidence. However, in Japan, L. leptolepis on wetter sites has been found to be quite susceptible to Armillariella attack. Armillariella needs to be recognized as a potential problem when planting on cutover sites, particularly those with oak. The most resistant species of larch is the European, with Japanese being the most susceptible and the hybrid being intermediate.

Butt rots occur occasionally but are not serious problems. Corticium galactinum and Phaeolus schweinitzii (Polyporus schweinitzii) are the two most aggressive fungi. There are also several heart rot fungi, four species of Fomes and Polyporus borealis but again are not serious problems.

As with the insect pests, larch has few disease problems. The proper selection of sites and seed sources, coupled with good management, should produce very acceptable plantings.

ANIMAL DAMAGE OF LARCH

Larch, like all other tree species, has its complement of animal antagonists. Foremost among these are porcupines. They damage both young and old plantations by feeding on bark and small shoots. A small 5-year-old larch planting near Wabeno, Wisconsin, was severely damaged by one or two porcupines that were allowed to feed unchecked (see Fig. 29). As a consequence, a large number of stems have been girdled or damaged and it is doubtful if many of the injured stems will recover. Small plantings put in near old growth timber tend to exaggerate the problem. Additional porcupine damage was noted in a European larch planting near Pembine, Wisconsin. The planting is now 20 years of age and the damage appears to have happened around age 15. There are many multiple and deformed tops. Control measures are being investigated. Poisioning has been suggested but the legality and environmentalist pressure may preclude the use of this approach. Trapping and/or shooting may be the most viable alternatives.

Figure 29. Damage by One or Two Porcupines Can be Quite Severe if Left Uncontrolled. Illustrated is the Girdling of a Five-Year-Old Larch Stem in a Small Replicated Planting in Northern Wisconsin. Small Plantings are Particularly Prone to Extensive Damage. It is Felt that Larger Acreages and Control Measures will Help Minimize the Impact of Porcupine Damage

Mice, voles, rabbits and hares will also produce some pressure on young stems. Little can be done to control these animals. It is felt that larger plantings will be able to absorb some damage and mortality without losing an unacceptable number of stems.

Deer will also provide browsing pressure and cause damage by rubbing antlers. Larch is capable of establishing a new dominant leader after being damaged; thus, long-term form problems should be avoided. Well-established larch is also quite vigorous and capable of rapid early growth, so exposure to deer pressure should be limited to only a few years.

Of minor importance is the damage caused by squirrels clipping cones and occasional new growth. Some squirrel damage has been noted on one small block of larch on the Ripco Test Area near Eagle River, Wisconsin.

The pressure provided by the animals listed should pose no surprises. They are common detriments to any planting program and, for the most part, produce severe damage primarily in localized situations or in years with conditions favoring the buildup of any particular species. Large plantations should minimize the effects of these animals.

PLANS FOR 1981-82

The overall level of activity on the project will be accelerated during the coming year. Special emphasis will be placed on selection of parent trees and vegetative propagation (grafting and rooting). Pulping of Japanese larch will be completed and wood quality evaluation will be completed on previously selected trees and extended to newly selected parent trees. Isozyme investigations will be expanded and the first two of five or six replicated plantings will be established. Additional 18- to 24-year-old Japanese and European larch plantations will be evaluated for site quality (soils) and insect and disease problems. Also planned are rooting studies and preliminary herbicide investigations of larch old-field and conversion plantings. Additional contacts are being established in Europe in an effort to obtain good quality seed for cooperator demonstration plantings.

## ACKNOWLEDGMENTS

The authors of this report are indebted to Robert Avery and John Lorenz for their assistance with grafting, nursery maintenance and field measurements and collections. The authors also wish to acknowledge the assistance of the Institute's Pulping Group for their work on the kraft pulping of larch, the Fiber Science Group for fiber dimension measurements and the Analytical Chemistry Group for lignin and extractives measurements. Great appreciation is also expressed to the U.S. Forest Service, Wisconsin DNR, and various company foresters for their help in locating selected trees.

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# TREE INFORMATION SHEETS

PROJECT TREE NO. ________ SEX ________ DATES: Discovered ________
Measured ________
LOCATION: ____________________ Cores Taken ________

| HEIGHTS (feet): | | DIAMETERS (inches): | | BARK THICKNESS (inches): | |
|---|---|---|---|---|---|
| Total | ____ | D.B.H. | ____ | D.B.H. | ____ |
| 3 Inch Top | ____ | 16.5 ft. | ____ | 16.5 ft. | ____ |
| 1st Live Branch | ____ | RINGS/INCH: | ____ | AGE: ____ + | ____ |

FORM:

1) Stem (1-5) ________ p - g
2) Branches
   a) Number ________
   b) Angle (°) ________
   c) Weight (1-5) ________ g - p
   d) Natural Pruning (1-5) ________ p - g
3) Crown
   a) Diameter (ft.) ________
   b) Exposure (0-4 sides) ________
   c) Class ________
   d) Deformities ________

SOIL INFORMATION:

| Horizon | Thickness | Texture | Remarks |
|---|---|---|---|
| $A_0$ | ____ | ____ | |
| $A_1$ | ____ | ____ | |
| $A_2$ | ____ | ____ | |
| B | ____ | ____ | |
| Water Table | ____ | | |

Topographic Information
Aspect ________
Slope ____ % ____
Topographic Position ________
________
Site Index ________

ASSOCIATED SPECIES: ____________________

DISEASE RECORD: No. Cankers, etc. ____________________

INSECT RECORD: ____________________

OTHER INJURY: ____________________

LOCATION WOOD SAMPLES: ________

LEAF COLLECTION:
Number ________
Location in Crown ________

CALCULATIONS:
Form Factor ________
Tree Volume ________
Crown Volume ________
Selection Index ________
Specific Gravity ________
Fiber Length (Age 30) ________

Discovered by: ________ Measured by: ________

REMARKS: Painted: ________

Members of Group Project 3409

LOCATION: State __________ County __________ Twp. __________ Range __________

Sec. __________ Other ________________________________________

MAP OF LOCATION:

OWNERSHIP INFORMATION:

CORE INFORMATION: Number Taken __________ Increment Borer Number __________

Equilibrium Moisture Content _____ % _____ Oven Dry Wt. Conversion Factor _____

| | Core No. 1 | Core No. 2 | Core No. 3 | Core No. 4 | Core No. 5 | Core No. 6 | Average |
|---|---|---|---|---|---|---|---|
| Length (mm) | ______ | ______ | ______ | ______ | ______ | ______ | |
| Eq. Mo. Con. Weight | ______ | ______ | ______ | ______ | ______ | ______ | |
| O.D. wt. | ______ | ______ | ______ | ______ | ______ | ______ | |
| Volume (cc) | ______ | ______ | ______ | ______ | ______ | ______ | |
| Sp.Gr. | ______ | ______ | ______ | ______ | ______ | ______ | ______ |

TABLE XXIII

PHYSICAL PROPERTIES OF UNBLEACHED KAPPA 50 PULPS

| Wood Type | No. of Revs. | CSF, mL | Density, g/cc | Burst Factor | Tear Factor | Breaking Length, km | TEA, kg-m/m$^2$ | Zero Span Breaking Length, km |
|---|---|---|---|---|---|---|---|---|
| 100% Jack pine | 0 | 725 | 0.529 | 46.2 | 182 | 6.30 | 5.0 | 19.8 |
| | 1,000 | 705 | 0.629 | 65.4 | 153 | 8.31 | 9.5 | 20.2 |
| | 5,000 | 510 | 0.717 | 87.0 | 122 | 10.82 | 14.6 | 20.9 |
| | 6,000 | 455 | 0.720 | 88.8 | 114 | 11.10 | 14.9 | 19.8 |
| | 7,500 | 345 | 0.744 | 95.2 | 111 | 11.15 | 15.6 | 20.0 |
| | 9,000 | 260 | 0.754 | 89.2 | 108 | 11.28 | 15.3 | 21.2 |
| 25% European larch | 0 | 710 | 0.513 | 49.9 | 189 | 6.50 | 5.4 | 19.2 |
| | 1,000 | 695 | 0.624 | 67.4 | 165 | 8.32 | 9.6 | 20.1 |
| | 5,000 | 530 | 0.708 | 87.6 | 122 | 10.76 | 14.8 | 20.2 |
| | 6,500 | 445 | 0.728 | 86.3 | 129 | 10.92 | 15.4 | 19.9 |
| | 8,000 | 360 | 0.724 | 94.2 | 123 | 10.99 | 15.0 | 19.9 |
| | 10,000 | 245 | 0.749 | 91.5 | 118 | 11.42 | 16.3 | 21.0 |
| 100% European larch | 0 | 720 | 0.506 | 34.8 | 196 | 5.68 | 4.3 | 17.9 |
| | 1,000 | 680 | 0.621 | 60.5 | 170 | 8.51 | 9.7 | 18.9 |
| | 5,000 | 505 | 0.703 | 81.8 | 120 | 10.16 | 13.0 | 19.4 |
| | 6,000 | 445 | 0.718 | 84.4 | 114 | 10.96 | 14.7 | 20.1 |
| | 7,500 | 365 | 0.729 | 88.6 | 112 | 11.15 | 16.1 | 19.8 |
| | 9,000 | 245 | 0.741 | 85.7 | 109 | 11.38 | 15.4 | 19.2 |
| 25% Hybrid (23 yr) larch | 0 | 720 | 0.509 | 41.9 | 217 | 6.07 | 4.7 | 19.0 |
| | 1,000 | 705 | 0.622 | 61.1 | 172 | 8.13 | 9.6 | 19.3 |
| | 5,000 | 540 | 0.705 | 84.2 | 130 | 10.37 | 14.9 | 19.1 |
| | 6,500 | 425 | 0.712 | 84.2 | 129 | 10.55 | 14.4 | 19.2 |
| | 8,000 | 320 | 0.736 | 90.8 | 127 | 10.85 | 15.6 | 19.3 |
| | 10,000 | 230 | 0.741 | 89.5 | 122 | 10.75 | 14.2 | 19.3 |
| 100% Hybrid (23 yr) larch | 0 | 760 | 0.464 | 31.9 | 216 | 5.06 | 3.3 | 17.2 |
| | 1,000 | 710 | 0.564 | 53.2 | 202 | 7.14 | 7.8 | 18.2 |
| | 5,000 | 565 | 0.557 | 73.5 | 149 | 9.32 | 12.8 | 18.0 |
| | 6,500 | 465 | 0.670 | 74.2 | 155 | 9.90 | 17.3 | 18.7 |
| | 7,500 | 390 | 0.686 | 77.4 | 141 | 9.58 | 13.5 | 18.3 |
| | 9,000 | 280 | 0.710 | 82.8 | 141 | 10.17 | 14.6 | 18.2 |
| 25% Hybrid (8 yr) larch | 0 | 740 | 0.528 | 40.6 | 165 | 6.51 | 6.4 | 18.4 |
| | 1,000 | 700 | 0.614 | 63.1 | 153 | 8.16 | 10.4 | 19.6 |
| | 5,000 | 570 | 0.694 | 82.6 | 115 | 10.35 | 14.6 | 18.2 |
| | 6,500 | 510 | 0.710 | 80.4 | 116 | 10.38 | 16.2 | 19.2 |
| | 7,500 | 480 | 0.712 | 83.4 | 114 | 11.13 | 17.2 | 19.0 |
| | 9,000 | 380 | 0.729 | 85.6 | 113 | 10.69 | 15.9 | 15.4 |
| 100% Hybrid (8 yr) larch | 0 | 710 | 0.544 | 38.1 | 113 | 6.40 | 6.2 | 13.9 |
| | 1,000 | 580 | 0.610 | 57.0 | 110 | 8.10 | 11.5 | 15.4 |
| | 5,000 | 430 | 0.634 | 64.8 | 98.8 | 8.60 | 12.7 | 15.9 |
| | 6,500 | 410 | 0.661 | 63.5 | 97.2 | 9.00 | 14.1 | 15.6 |
| | 7,500 | 365 | 0.680 | 64.2 | 92.0 | 9.20 | 14.4 | 16.0 |
| | 9,000 | 330 | 0.687 | 66.2 | 98.5 | 8.90 | 13.9 | 15.6 |

TABLE XXIV

PHYSICAL PROPERTIES OF BLEACHED KAPPA 30 PULPS

| Wood Type | No. of Revs. | CSF, mL | Density, g/cc | Burst Factor | Tear Factor | Breaking Length, km | TEA, $kg\text{-}m/m^2$ | Zero Span Breaking Length, km | Scatter Coefficient, $cm^2/g$ |
|---|---|---|---|---|---|---|---|---|---|
| 100% Jack pine | 0 | 730 | 0.612 | 29.0 | 269 | 4.60 | 6.7 | 17.0 | -- |
| | 2,000 | 640 | 0.709 | 84.9 | 136 | 10.24 | 17.8 | 19.6 | 171 |
| | 5,500 | 455 | 0.739 | 94.1 | 118 | 11.46 | 19.8 | 20.3 | 143 |
| | 8,000 | 345 | 0.756 | 95.2 | 124 | 11.65 | 19.9 | 21.8 | 135 |
| | 9,500 | 285 | 0.759 | 93.2 | 113 | 11.55 | 19.3 | 20.8 | 135 |
| 25% European larch | 0 | 710 | 0.602 | 27.4 | 286 | 4.80 | 6.6 | 17.2 | 278 |
| | 2,500 | 595 | 0.720 | 81.5 | 127 | 10.80 | 15.9 | 20.4 | 164 |
| | 4,500 | 500 | 0.734 | 88.3 | 115 | 11.30 | 17.0 | 20.3 | 146 |
| | 7,500 | 360 | 0.755 | 89.6 | 114 | 11.20 | 17.2 | 20.0 | 140 |
| | 9,000 | 275 | 0.765 | 92.1 | 108 | 12.00 | 18.5 | 20.9 | 131 |
| 100% European larch | 0 | 680 | 0.637 | 36.3 | 263 | 5.5 | 8.1 | 16.8 | 254 |
| | 1,000 | 620 | 0.707 | 74.5 | 161 | 10.2 | 14.8 | 19.2 | 190 |
| | 3,000 | 495 | 0.734 | 88.8 | 129 | 11.1 | 16.0 | 20.6 | 155 |
| | 6,000 | 340 | 0.747 | 92.3 | 118 | 11.1 | 15.7 | 19.6 | 138 |
| | 8,000 | 260 | 0.763 | 94.8 | 114 | 10.7 | 13.2 | 20.7 | 139 |
| 25% Hybrid (23 yr) larch | 0 | 720 | 0.584 | 29.9 | 278 | 4.5 | 5.8 | 16.9 | 276 |
| | 2,500 | 600 | 0.736 | 78.1 | 121 | 10.2 | 14.9 | 19.2 | 160 |
| | 4,500 | 490 | 0.744 | 90.8 | 123 | 11.2 | 16.4 | 19.6 | 145 |
| | 6,500 | 370 | 0.751 | 90.7 | 112 | 11.3 | 16.6 | 20.2 | 138 |
| | 9,700 | 280 | 0.718 | 89.1 | 124 | 11.3 | 17.1 | 19.6 | 134 |
| 100% Hybrid (23 yr) larch | 0 | 710 | 0.557 | 23.1 | 250 | 3.9 | 4.13 | 16.1 | 259 |
| | 2,000 | 615 | 0.679 | 74.8 | 175 | 9.6 | 14.3 | 18.9 | -- |
| | 4,500 | 540 | 0.692 | 86.9 | 145 | 10.8 | 16.3 | 19.2 | -- |
| | 6,500 | 325 | 0.719 | 88.6 | 144 | 11.0 | 16.8 | 19.8 | 134 |
| | 8,000 | 235 | 0.729 | 88.1 | 130 | 11.2 | 16.6 | 19.2 | 129 |
| 25% Hybrid (8 yr) larch | 0 | 730 | 0.636 | 42.8 | 224 | 5.9 | 8.9 | 17.1 | 270 |
| | 500 | 670 | 0.700 | 73.4 | 154 | 9.1 | 15.3 | 18.3 | 213 |
| | 1,500 | 590 | 0.737 | 87.1 | 132 | 10.4 | 17.2 | 19.3 | 174 |
| | 3,500 | 470 | 0.763 | 91.2 | 113 | 11.4 | 18.3 | 19.6 | 146 |
| | 5,000 | 400 | 0.776 | 96.8 | 106 | 11.9 | 19.4 | 19.1 | 138 |

Topophysis - Abnormal growth that occurs in a graft when scion material is collected from the wrong branch positions.

Pulping Terms

Breaking length - The length of a strip, usually expressed in meters, which would break of its own weight when suspended vertically.

Bursting strength - The hydrostatic pressure in pounds per square inch required to produce rupture of the material when pressure is applied at a controlled increasing rate through a rubber diaphragm to a circular area.

CEDED bleaching - Sequence of chlorination, alkali extraction, chlorine dioxide, extraction and chlorine dioxide.

Freeness - A measure of the rate with which water drains from a stock suspension through a wire mesh screen or a perforated plate. It is also known as "slowness" or "wetness" according to the type of instrument used in its measurement and the method of reporting results.

Furnish - The mixture of various materials that are blended in the stock suspension from which paper or board is made. The chief constituents are the fibrous material (pulp), sizing materials, wet-strength or other additives, fillers and dyes.

Handsheet - A sheet made from a suspension of fibers in water, with or without the addition of sizing, loading or coloring agents. Each sheet is formed separately by draining a pulp suspension on a stationary mold called a sheet mold. It is generally used for testing the physical properties of the pulp and/or the combinations of pulp with other material, in which case the sheet must be formed in accordance with standard procedures.

Kappa no. - Related to the amount of lignin left in the pulp. Decreasing numbers mean less lignin left in the pulp.

Tearing resistance - The force required to tear a specimen under standardized conditions. There are three terms in common usage: (1) internal (or continuing) tearing resistance, wherein the edge of the specimen is cut prior to the actual tear. The value is commonly expressed in grams of force required to tear a single sheet. (2) "Edge tearing resistance." (3) Torsion tearing resistance of paper or paperboard is the energy expended in propagating a tear when the tearing force is applied in such a manner as to create a twist or torque.

Tensile strength - The force, parallel with the plane of the paper, required to produce failure in a specimen of specified width and length under specified conditions of loading. This definition must be distinguished from that which is commonly used in engineering practice which expresses the tensile strength in force per unit area. In the paper industry, it is expressed as load per unit width or as "breaking length."

Zero-span tensile strength - The tensile strength of a sheet of fibrous material, measured with special jaws, at an apparent initial span of zero. It is an indication of the strength of the material comprising the fiber.