REPORT

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by Julius V. Hofmann for the degree of Doctor of Philosophy. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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May 7 1914

NATURAL REPRODUCTION OF CONIFEROUS FORESTS.

A Study of the Pathological and Ecological factors influencing seed germination and the establishment of seedlings with special reference to reproduction after fires and logging operations.

A THESIS

SUBMITTED TO THE FACULTY

OF THE

GRADUATE SCHOOL

OF THE

UNIVERSITY OF MINNESOTA

March 14, 1914

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF Ph. D.

ACKNOWLEDGMENTS.

In the pathological work acknowledgment is made to Dr. E. M. Freeman, under whom the laboratory work was done, and to Mr. Carl Hartley who assisted in planning the experiments carried on at the Kansas and Garden City Nurseries, and also prepared part of the detailes records, assisted by Miss Faye M. Hartley, also to Mr. B.R.H.d'Allmand for assistance in the conduct of the experiments. A brief summary by Hartley, in collaboration with Dr. Theodore C. Merrill, of experiments in these and several other nurseries will appear in the April 1914 number of Phytopathology.

In the ecological work acknowledgment is made to Dr. F. E. Clements, who assisted in planning many experiments in the laboratory work upon which much of the field work was based later, and to Professor J. P. Wentling, under whom the silvicultural work was done, for many suggestions in the development of the work and in working up the final results.

The author also owes much to the co-operation of the Forest Service, especially to Mr. D. R. Brewster and Mr. H. J. A. Grossmann in the migration and establishment study at the Priest River Experiment Station and to Mr. T. T. Munger, Mr. C. J. Kraebel, and Mr. R. Watson in the migration and establishment study at the Wind River Experiment Station.

Credit is also given the Forest Service for plates numbered 7, 8, 9, 10, 11, 12, 14 and 15, although all except numbers 14 and 15 were taken by the author. All other plates are original.

The Bureau of Plant Industry has been given permission to use the plates in Part I.

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Part I.

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The Ecological and Pathological factors which influence the development of the forest tree seedlings must be known in order to account for the presence or absence of reproduction in the field or to intelligently handle the problems of the nursery. Since the work presented here naturally divides itself into two parts, Pathology and Ecology, iy will be taken up in two separate parts.

Part I. taking up the pathological problems is mostly confined to the laboratory and nursery work since most of the pathological problems that can be dealt with at all are those of the nursery. The pathological problems of the field are usually such that little can be done toward preventing or checking them but those of the nursery are under conditions which can be controlled and much can be done to prevent and check the diseases.

Part II. deals with the ecological factors influencing the germination and establishment of the seedlings and since the factors concerned are the basis of the success of the reproduction following any area where the forest has been removed by fire or cutting these factors must be known in order to approximate the ones most favorable to securing the desired reproduction on areas to be cut over.

During the winter of 1911 and 1912 work was done on "Damping Off" at the University of Minnesota by making cultures of the disease taken from different hosts and aerial cultures for inoculation purposes and the entire summer of 1912 was spent on control methods in the Garden City and Kansas Nurseries near Garden City, Kansas.

In October, 1911, Pythium debaryanum was isolated by exposing plates at a height of thirty feet above ground and was kept in culture until February, 1912. Inoculations with cultures of the fungus obtained from the air were made by puncturing with a needle individual seedlings grown on heat sterilized soil, and applying small masses of mycelium directly to the seedlings. Results were as follows:

Picea canadensis	100 inoculations,	15 successful.
Pinus ponderosa	100 inoculations,	22 successful.

Inoculations were made on Picea canadensis 3 to 5 days after germination (plants above ground) and on Pinus ponderosa 2 to 6 days after germination (plants above ground). The culture contained some molds but in the dead seedlings no trace of any parasitic fungi was found except Pythium. The first signs of fungus attack was noticed 48 hours after inoculations.

Cabbage Cultures

Cultures were taken from cabbage plants about two weeks old that were dying of typical damping-off. Cultures were plated out and then the Pythium taken from the plates and replated before using it for inoculation purposes. Trays containing heat sterilized soil were sown to Picea canadensis and Pinus ponderosa and inoculated at marked points with mycelium from the cultures taken from the cabbage. All inoculations of the soil were approximately 3 inches apart each way and the colonies did not grow together until it was evident which ones were effective. The first signs of attack were noticed the third day after inoculations. Inoculations were made just as the seedlings were appearing above the ground.

Results were as follows:

Picea canadensis	Inoculation at 50 points,	24 effective.
Pinus ponderosa	Inoculation at 50 points,	14 effective.

Salsola tragus cultures

Cultures taken from plants about one week old where nearly all of them were dying of damping-off. Cultures madè by planting pieces of the stems of the thistles in culture media and then plating out the Pythium. Inoculations were made in sterilized soil the same as with the cabbage cultures. Inoculations were made when the first seedlings appeared above ground and the first effect of the fungi was noticed three days after the inoculations were made. The cultures contained some molds, but Pythium was the only parasitic fungus found in the attacked seedlings.

Results were as follows:

Picea canadensis	Inoculations at 50 points,	32 effective.
Pinus ponderosa	Inoculation at 50 points,	20 effective.

Radish Cultures

Cultures taken from radish plants about three weeks old in which the damping-off was causing rot and killing the plants. Parts of the radishes were planted in the culture media and then the pythium taken from the plates and put into culture. The material used for the inoculations contained some molds but as in the previous cases only pythium was found in the killed seedlings after inoculation. Inoculations were made when the first seedlings were appearing above ground and the first effect was noticed in the Picea canadensis 4 days after inoculation and in the Pinus ponderosa 7 days after inoculation. Trays containing heat sterilized soil were used.

Results were as follows:

Picea canadensis	Inoculation at 50 points, 18 effective.
Pinus ponderosa	Inoculation at 50 points, 7 effective.

In the work done in the green-house no infections occurred except at the points inoculated so it appeared that all of the infections were due to inoculations.

WORK AT GARDEN CITY AND KANSAS NURSERIES

These two nurseries are located near Garden City, Kansas and although they are only two and one-half miles apart, the conditions vary greatly as to soil conditions. The soil at the Garden City Nursery consists of a heavy, black clay loam while the soil at the Kansas Nursery is very sandy being almost pure sand in some places. These differences in the texture of the soil cause a great difference in the soil moisture content and in the soil temperature, consequently the fungicides that are effective at one nursery are not effective at the other. The soil at the Garden City Nursery contains such a high percent of alkali that the acid treatments failed while the same treatments were at least partially successful at the Kansas Nursery. The soil at the Garden City Nursery is too heavy for small seedlings such as ~~the~~ Pinus divaricata and Pinus sylvestris to germinate well as the seedlings cannot push up through the heavy soil so it is necessary to mix sand with the soil used to cover the seed of the species having these small seeds. When the seedlings break through the soil and push up the soil with them which forms a chamber at the base of the seedling making a moist shaded chamber which produces ideal conditions for the damping-off fungi to develop. Many of the seedlings are attacked and killed while in this stage. The sandy soil at the Kansas Nursery contains a high percent of silicates and the acid used as a fungicide is not so readily neutralized when applied to the soil, but the sand allows very rapid percolation of rainfall and any solution applied.

Previous work on damping-off fungi, verified by Hartley and Spaulding, established the fact that these fungi are essentially soil fungi so the methods of controlling and preventing damping-off at these nurseries were taken up as soil fungi problems.

In the soil treatments the following chemicals were used: Commercial nitric acid, commercial sulphuric acid, commercial hydrochloric acid, copper sulphate, iron sulphate, zinc chloride, mercuric chloride, sodium chloride, formaldehyde, ammonium hydroxide, lime, bordeaux mixture, potassium hydroxide and heat peaseuriza-tion of the soil. These chemicals were used separately and in various combinations.

Here as in all previous work by Hartley, chemical injury was encountered and this is one of the most difficult problems in the chemical treatments of the soil. When fungicides are applied at time of seeding or earlier, in strengths sufficient to be effective, there is danger of injury to seedlings at time of germination and the first few days following germination. As had been found by Hartley at the Halsey, Nebraska nursery,* seedlings that were chemically injured have the growing apices of the roots damaged thus preventing the root from continuing growth, so the seedling is dependent on the short root already formed until it can send out adven-titious laterals and again establish itself. For this reason it must have sufficient water during this period so it will either prevent the chemical injury or aid the seedling in establishing itself again if the injury occurs. Frequent light waterings such as had been used at Halsey were also sufficient to prevent injury from most fungicides at these nurseries. It was found for potassium hydroxide and ammonia at the Kansas nursery, as had been found for formaldehyde and mercuric chloride in the preceding work above referred to at the Halsey nursery, that when application was made to the bed at time of sowing dormant seed were killed.

In order to treat soil successfully the chemical and physical condition of the soil must be known in order to know whether acids or toxic salts should be used in the treatments because chemicals applied to the soil may be lost by combina-tion with other chemicals or by neutralization or if the soil is too porous the effect of the treatment may be lost by percolation to a depth where it would not be effective.

*Hartley, Carl. The use of soil fungicides to prevent damping-off of coniferous seedlings. Proc. Soc. Am. For., v. 7, p. 96, 1912.

Sulphuric acid 5 days before seeding.

Garden City Nursery.

Pinus divaricata sown June 29, 1912, drills, 1800 seeds per sq. ft., 80% shade, Pettis frame. Protection against reinfection, board sides 4" high. Plots sown 2' x 4', treated 3' x 4'. Two sq. ft. in each plot counted. Days to germinate 9. Watered 4 pints per sq. ft., 2 days after treatment and then 1 pint per sq. ft once and twice daily according to the weather. 1½ pails sand applied to plot and 1½ pails to the surface. Chemical injury none.

Results as follows:

TABLE NO. I.

Plot	No. seedlings appeared per sq. ft.	No. per 100 seeds sown	Percent of death after seedlings appeared.							Survival per sq. ft.	Survival per 100 seed sown	Treatment	
			7/9 1st - 10th day	7/12 10th - 13th day	7/16 12th - 17th day	7/20 17th - 21st day	7/30 21st - 31st day	8/8 31st - 40th day	Total 1st to 40th day			Oz. acid per sq. ft.	Pts. solution
A	449	25	0	6	48	49	63	29	94	29	1.6	1/2	2
B	440	24	0	4	33	68	59	29	94	26	1.4	5/8	2
C	514	28	15	34	70	86	50	0	99	4	0.2	Check	
D	394	22	0	7	45	60	81	50	98	8	0.4	11/16	2

Treatment increased yield five times on the average and seven times in best plot.

Cultures of the diseased seedlings showed Pythium debaryanum and Fusarium sp. in all of the plots showing that the treatment was not strong enough to keep out the fungi although they were as strong as some treatments that had proven effective in some other localities so the effect of the acid must have been lost, due to the alkali in the soil.

Sulphuric acid four days before sowing, lime at sowing.

Garden City Nursery.

Pinus divaricata sown June 5, 1912, broadcast, 1000 seeds per sq. ft. Protection against reinfection, solid boards 5" above and 5" below surface, plots A, B, C, D permanently covered with oiled muslin. Plots sown 1' x 1', treated the same. Entire area counted. Days to germinate 13. Watered by sub-irrigation, perforated tin pipe 8" down. Shade 50%, high. Chemical injury: Germination almost 0 in plot D all that came up was chemically injured; B and F were least hurt; all other treatment considerably.

Results as follows: The treated covered plots produced on the average 82 seedlings per sq. ft. compared to 0 in the untreated check plot and the best plot produced 121. The uncovered treated plots produced on the average 82 seedlings per sq. ft. as compared to 97 produced by the untreated check plot, but the best plot produced 172.

Cultures from the dead and dying seedlings gave Rhizoctonia sp. and Fusarium sp., the Fusarium being obtained from the tops of the seedlings.

It seems that the neutralization of the acid by the lime left the soil without any soil fungi yet neutral so the parasitic fungi had full sway and especially favorable conditions where reinfection occurred, as was indicated by Hartley's earlier results at Halsey.

Garden City Nursery.

Ten series of sulphuric acid at time of seeding using from ¼ oz. per sq. ft. to 3 oz. applied in 2 pts. of water per sq. ft. 67 treated plots averaged 35 seedlings per sq. ft. survival. 26 untreated plots averaged 40 seedlings per sq. ft. survival. Species used. Pinus divaricata, Pinus laricio, Pinus sylvestris, Pinus austriaca, Pinus ponderosa. Burlap soaked with Bordeaux mixture used on one of the plots to prevent reinfection, but failed.

One series of Pinus divaricata treating 2 plots with sulphuric acid 5 days before seeding and neutralizing with lime at time of seeding and 3 plots with sulphuric acid at time of seeding. Plots treated with sulphuric acid at time of seeding gave survival of 32 seedling per sq. ft. as compared to 6 in the check plot and the plots treated before seeding and neutralized with lime at time of seeding gave an average survival of 8 seedlings per sq. ft. as compared to 6 in the check plot.

Three series treated with sulphuric acid 11, 16 and 18 days after a good stand had appeared. Pinus ponderosa, Pinus austriaca, Pinus divaricata. Percent of death of seedlings after treatment had time to take effect: Average of 5 treated plots 31%, average of 5 check plots 31%. Strengths varying from ¼ to 2 oz. acid per sq. ft. were used.

Two plots of Pinus laricio treated with mercuric chloride at time of seeding produced an average stand of 31 seedlings per sq. ft. as compared with 3 in the untreated plot. One plot treated with 3/32 oz. mercuric chloride and ¼ oz. hydrochloric acid produced 89 seedlings per sq. ft. as compared with 3 in the untreated plot and one plot treated with 3/16 oz. mercuric chloride and ¼ oz. sodium chloride produced 60 seedlings per sq. ft. as compared with 3 in the untreated plot.

Two plots of Pinus laricio treated with iron sulphate produced on the average 11 seedlings per sq. ft. as compared with 9 in the untreated plot.

One series of Pinus sylvestris treated with Nitric acid. Four treated plots produced on the average 111 seedlings per sq. ft. as compared with 17 in the untreated plot.

One series of Pinus sylvestris treated with Hydrochloric acid. Six treated plots produced on the average 91 seedlings per sq. ft. as compared with 26 in the untreated plot.

Cultures taken from a large number of the plots of the above series showed Rhizoctonia sq. and Fusarium sp. in all of them.

Heat Pasteurization.

Soil was put into an oven and raised to a temperature of 180 degrees Fahrenheit for 30 minutes or more and kept moist. This soil was put into frames one foot square having the board sides 5 inches above ground and 5 inches below. The top was covered with oiled muslin cloth and the whole series sub-irrigated. Eight plots were used in this series. One as a check being uncovered and one as a check in which the soil was not pasteurized. The other plots were uncovered at intervals of 8 days after seeding. The object of the experiment was to determine the period in the growth of the seedling at which it is most subject to reinfection from the air. The entire series failed so the results were in no way indicative except that the reinfection caused more serious loss in the pasteurized plots than in the check which was not pasteurized perhaps due to the fact that the other soil fungi were killed in the heated soil, so soil fungi competition was removed. * The seedlings were to some degree etiolated and weakened when uncovered so were more subject to attack. Pinus divaricata was used.

This experiment was duplicated with the same results, the seedlings uncovered first giving the greatest percent survival perhaps due to the seedlings being more sturdy and resistant.

Two other series, one with Pinus laricio and one with Pinus sylvestris in which two plots were heat pasteurized, two treated with sulphuric acid and one check in each series, gave about equal germination in all of the plots, but a less percent

* This result confirms results obtained by Hartley with soil heated in the same way the preceding season at the Halsey nursery.

survival in the heat pasteurized plots apparently due to reinfection.

Cultures from different plots in these series showed Rhizoctonia sp. and Fusarium sp. The Fusarium was found in the tops of the seedlings.

PLATE I.

View under high shade frame, 50% shade, showing the sub-irrigated plots covered with oiled muslin on the right and in the background section of the high shade frame enclosed with burlap walls to prevent drifting of sand and dust in order to determine reinfection on the treated plots within this enclosure.

Formalin applied before seeding.

Garden City Nursery.

Pinus divaricata sown June 12, 1912, drills, 1500 seeds per sq. ft. High shade, 50%. Protection against reinfection, 5 series surrounded permanently by burlap fence 6 ft. high, double lower three feet.

Plots sown 2' x 4', treated 4' x 6'. Three sq. ft. in each plot counted. Days to germinate 11. Watering, same as ordinary nursery. Chemical injury, very serious in plot K and some in J.

Results were as follows:

TABLE NO. II.

Plots	Germination per sq. ft.	Complete counts on two drills										Treatment			
		% dead 6/27 0 - 4 days	% dead 7/2 4 - 9 days	% dead 7/6 9 - 13 days	% dead 7/10 13 - 17 days	% dead 7/17 17 - 24 days	% dead 7/20 24 - 27 days	% dead 7/30 27-37 days	% dead 8/8 37 - 46 days	% dead total 0 - 46 days	Survival per sq. ft. 46 days old	Fungicides	Ounces per sq. ft.	Pts. solution per sq. ft.	Time of application
A	331	0	11	39	89	43	6	16	38	98	8	F	3/8	3	14 da. before
B	127	4	57	65	39	3	13	0	7	93	9		Check		
C	473	0	4	9	26	36	9	14	2	68	151	F	3/4	3	14 da. before
D	671	0	8	15	14	29	19	54	0	68	216	F	3/4	3	10 da. before
E	103	6	50	49	34	2	6	0	2	86	14		Check		
F	405	0	0	0	1	8	3	2	0	17	337	F	3/4	3	6 da. before
G	546	0	0	1	9	6	2	9	6	29	388	F	9/16	3	14 da. before
H	86	16	45	40	37	13	7	0	5	86	12		Check		
J	382	0	4	3	28	41	19	14	10	76	93	F A	9/16 3/8	3 2	14 da. before at seeding
K	182	0	12	13	46	34	5	4	4	76	43	A	3/8	2	at seeding

F = Formalin - A = Commercial sulphuric acid.

The formalin treatments increased the yield 220 times and the treatment of formalin and sulphuric acid combined increased the yield 11 times. The acid treatment alone increased the yield 11 times. The acid injury was the cause of the low yield in the acid treated plots.

Cultures of the dying seedlings of the different plots showed the presence of Pythium debarryanum, Fusarium sp. and Rhizoctonia sp.

PLATE II.

View of the series treated with Formalin before seeding. The first plot in the foreground is Plot C, the next one plot D, etc. Table No. II shows the results of this series.

Copper sulphate applied at time of seeding

Garden City Nursery.

Pinus austriaca sown June 8, 1912, drills, 800 seeds per sq. ft. High shade 50%. Protection against reinfection, none. Plots sown 2' x 4', treated 4' x 6'. Three sq. ft. counted in each plot. Days to germinate 9. Watering, same as ordinary nursery. Chemical injury, very slight in plots A & C.

Results were as follows:

TABLE No. III.

	Complete Counts on two drills												Ounces per sq. ft.	
Plot	Germination per sq. ft.	% dead 6/21 0 - 4 days	% dead 6/25 3 - 7 days	% dead 6/29 7 - 11 days	% dead 7/5 11 - 17 days	% dead 7/9 17 - 21 days	% dead 7/16 21 - 28 days	% dead 7/20 28 - 32 days	% dead 7/30 32 - 42 days	% dead 8/5 42 - 48 days	Total dead 0 - 49 days	Survival per sq. ft. 49 days old	Treatment	Solution per sq. ft.
A	382	0	0	1	3	1	15	1	3	3	25	285	3/8 $CuSO_4$	2 pts.
B	96	19	32	37	31	13	2	3	5	4	82	17	Check	
C	445	0	0	0	7	3	5	1	4	3	21	351	1/2 $CuSO_4$	2 pts.

Treatment increased the yield 19 times.

PLATE III.

View of series treated with Copper sulphate.

Plot C in foreground, B **check** in middle and Plot A near fence.

Table No. III gives the results of this series.

Zinc Chloride applied at time of seeding.

Garden City Nursery.

Pinus divaricata sown June 8, 1912, drills, 1800 seeds per sq. ft. High shade 50%. Protection from reinfection, 5 series surrounded permanently by burlap fence 6 ft. high, double lower three feet.

Plots sown 2' x 4', treated 4' x 6'. Three sq. ft. in each plot counted. Days to germinate 10. Watering, same as ordinary nursery. Chemical injury, none.

Results were as follows:

TABLE NO. IV.

	Complete counts on two drills												Ounces per sq. ft.	
Plot	Germination per sq. ft.	% dead 6/21 0 - 3 days	% dead 6/25 3 - 7 days	% dead 6/29 7 - 11 days	% dead 7/5 11 - 16 days	% dead 7/9 16 - 20 days	% dead 7/16 20 - 27 days	% dead 7/20 27 - 31 days	% dead 7/30 31 - 41 days	% dead 8/5 41 - 47 days	Total dead 0 - 47 days	Survival per sq. ft. 47 days old	Treatment	Solution per sq. ft.
A	448	3	26	35	11	11	10	1	13	1	72	126	9/32 $ZnCl_2$	2 pts.
B	93	42	81	70	0	11	25	0	0	0	98	2	Check	
C	802	.3	14	11	5	2	6	.4	4	1	36	517	3/8 $ZnCl_2$	2 pts.
D	982	0	4	6	2	2	5	0	2	.3	19	793	1/2 $ZnCl_2$	2 pts.

The treatment increased the yield 718 times. Cultures of the dying seedlings of the untreated plot and the attacked seedlings of the treated plots showed the presence of Fusarium sp. and Rhizoctonia sp.

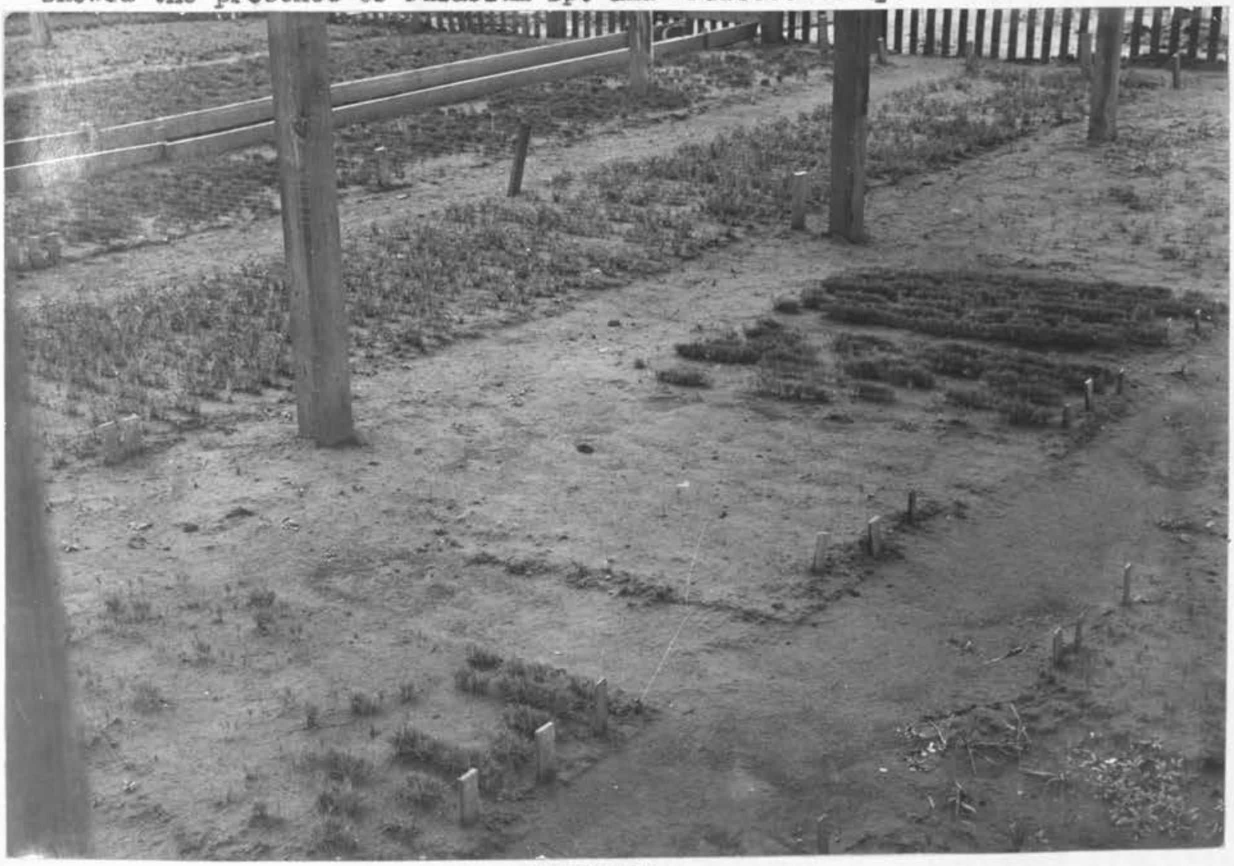

PLATE IV.

Series treated with Zinc chloride shown in the foreground. Plot in the lower left hand corner was treated with 1 1/8 oz. zinc chloride per sq. ft., the next plot is untreated, the third plot treated with 1½ oz. zinc chloride and the fourth plot was treated with 2 oz. Zinc chloride per sq. ft. The results are very clearly shown by the surviving stands in direct relation to the amount of the Zinc chloride applied. Results shown in Table No. IV.

Kansas Nursery.

One series of Formalin 14 days before seeding with Pinus sylvestris. Entire series failed although germination was about equal in all of the plots. Most of the seeds were killed by the formalin just as they began to germinate.

One series of Pinus divaricata treated with sulphuric acid 3 days before seeding and neutralized with lime at time of seeding. The entire series was covered with muslin and sub-irrigated. Germination was exceptionally rapid and good in all of the plots, but the loss was very heavy in the untreated plot right at germination and the seedlings in the treated plots survived for 10 days and then began to die rapidly due to reinfection. After reinfection occurred the seedlings continued to die at a rapid rate until all of the seedlings of the entire series were dead.

Apparently the absence of soil fungi competition gave the parasitic fungi full control and a chance for rapid development.

Two series treated with sulphuric acid. (Pinus ponderosa, Pinus sylvestris, Pinus laricio).

Eighteen treated plots produced on the average 107 seedlings per sq. ft. compared to an average of 49 per sq. ft. on 8 untreated plots.

Sulphuric acid at time of sowing.

Kansas Nursery.

Pinus divaricata sown June 4, 1912, drills, 1800 seeds per sq. ft. Pettis frame, 50% shade. Protection against reinfection, tight board sides 8 inches high. Plots sown 2½' x 4', treated 3' x 4'. Two sq. ft. counted in each plot. Days to germinate 11. Watering, 5 pints per sq. ft. two days after seeding and then 1 pint daily throughout the series. Chemical injury, serious in plots F & H and considerable in D.

Results were as follows:

TABLE NO. V.

Plot	Complete counts on two drills													Treatment	
	Germination per sq. ft.	% dead 6/19 0 - 4 days	% dead 6/24 4 - 9 days	% dead 6/26 9 - 11 days	% dead 6/29 11 - 14 days	% dead 7/3 14 - 18 days	% dead 7/8 18 - 23 days	% dead 7/11 23 - 26 days	% dead 7/15 26 - 31 days	% dead 7/20 31 - 36 days	% dead 7/29 36 - 45 days	% dead 8/9 45 - 57 days	% dead total 0 - 57 days	Survival per sq. ft., 57 days old	Ounces acid per sq. ft.	Pts. solution per sq. ft.
A	911	0	0	1	0	4	4	10	5	3	1	1	27	669	3/8	3
B	817	0	0	0	0	1	1	2	3	11	5	9	28	592	15/32	3
C	885	1	5	4	20	55	36	30	8	15	7	3	90	93	Check	
D	732	0	0	0	0	8	10	26	23	26	28	4	76	175	9/16	3
E	884	0	0	0	0	1	14	21	13	11	21	18	66	305	3/8	3
F	624	0	0	0	0	2	13	24	19	36	31	14	80	126	15/32	3
G	766	4	20	25	49	45	73	100	0	0	0	0	100	0	Check	
H	801	0	5	3	28	49	59	54	74	30	0	21	99	8	9/16	3

Treatment increased the yield 7 times. Cultures of the dying seedlings of all of the plots showed the presence of Pythium debarryanum and Fusarium sp. in all of them.

PLATE NO. V.

View of plots of Pinus ponderosa in series treated with sulphuric acid at the Kansas Nursery. The stakes in the middle of the bed show the division of the plots. The third plot is untreated. Beds shown in the background show the method of protecting the beds against reinfection.

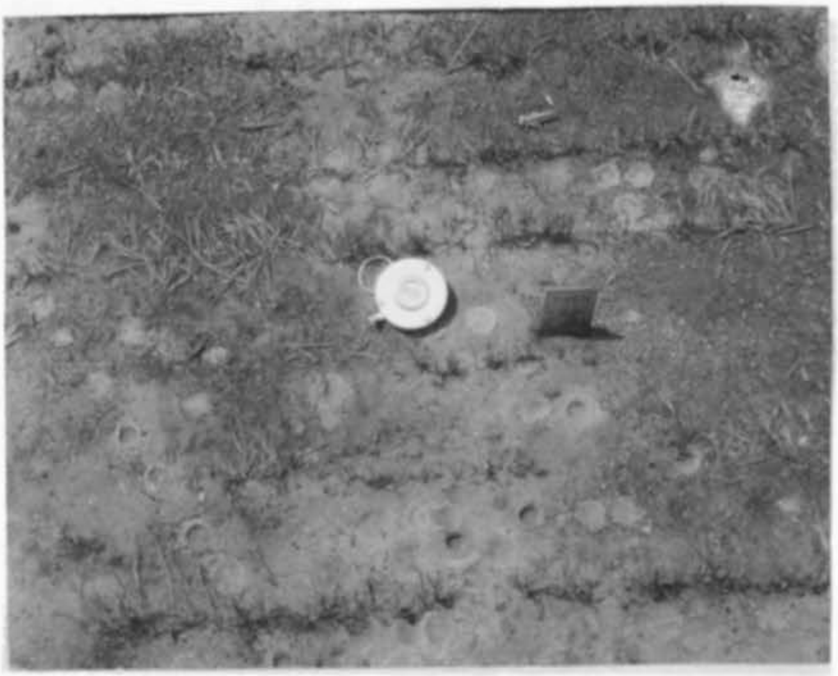

PLATE NO. VI.

Showing Pinus divaricata seedlings attacked by damping-off in an untreated plot in the Kansas Nursery. This shows how they are attacked even sometime after germination.

These experiments show that the toxic salts are the best fungicides in the heavy loam soil of the Garden City Nursery. The acids all failed because of the alkali in the soil, so even if the treatment gave initial sterilization of the soil there was not sufficient protection to prevent re-infection. The Zinc chloride and Copper sulphate gave the best results and will undoubtedly prove to be the fungicides to be used in this nursery.

In the sandy soil of the Kansas Nursery the sulphuric acid gave the best results and would be a very effective fungicide if the acid injury can be avoided by frequent watering, which is possible if the beds are watered every day.

Pythium was found working at depths of 6 and 7 inches in the soil which shows that the fungicide must be applied so it will sterilize the soil to this depth and as air cultures showed the presence of the spores in the air it is very evident that the seedlings must be protected from reinfection from the air and the only way this can be done is to have the effect of the chemicals applied, remain in the soil until the seedlings are old enough to resist the fungi.

SUMMARY.

Sulphuric acid is the best soil fungicide for damping-off in light, sandy soils.

Other acids did not give any beneficial results perhaps due to their breaking down and combining with other elements.

The toxic salts proved to be the best soil fungicides in the alkali or heavy soils.

Zinc chloride gave the best results although very good results were also obtained with Copper Sulphate.

When sulphuric acid is used special watering is necessary during germination and the early establishment of the seedling to prevent chemical injury by the concentration of the acid at the surface.

Ammonia, Potassium hydroxide, Mercuric chloride and Formalin were the only chemicals among those used that will kill dormant seed, so these must be applied before seeding and allowed to evaporate or percolate into the soil before the seed is sown.

Pythium debaryanum spores are disseminated through the air so initial sterilization is not sufficient but the seedlings must have protection from reinfection as well.

Pythium debaryanum works most vigorously at the surface but will spread rapidly at depths of 3 and 4 inches and has been found working at depths of 6 and 7 inches, hence the soil must be sterilized to this depth to insure thorough sterilization.

Pythium debaryanum is a cool temperature organism and does the most damage in the spring and during cloudy days in summer.

Pythium debaryanum is readily transferred from one of its hosts to the other as shown by the inoculation work done,

Fusarium sp. is a warmer temperature organism and does the most damage in later summer. It works in the tops of the seedlings as well as in the roots but most of the damage is done in the roots.

Rhizoctonia sp. is also a later summer fungus due to being a warmer temperature organism than Pythium. It works on various hosts but so far as was found in this work, is confined to the roots of the seedlings.

PART II.

AN ECOLOGICAL STUDY OF CONIFEROUS SEEDS AND SEEDLINGS AS TO MIGRATION AND ESTABLISHMENT.

Forests have covered some portions of the earth's surface ever since the evolution of the plant kingdom produced the woody tissued plants known as trees. Wherever the forests have gained possession of the ground they have held it permanently and have steadily encroached upon the surrounding territory as far as the climatic conditions made it possible for the trees to establish themselves.

The forest has successfully withstood the attacks of its natural enemies such as fire, insects, disease, wind and flood and has only been removed from areas which it once occupied by such far reaching agencies as glaciers and changes of climatic conditions making the tree growth impossible, where, even in those regions, it is again migrating back to the lands from which it was swept as soon as the climatic conditions are favorable to its establishment, as shown by the great forested regions of the Lake States of the United States. Thus the forest is truly eternal when left to the laws of nature,and it is only since the advent of man, with all his devastation and exploitation, that the decline of the forest began.

To impress us with the devastated waste left in the wake of man's exploitation, we have only to look at the barren, eroded mountain slopes of China, France, Spain, and those of our own country, all, at one time covered with a magnificent virgin forest which had withstood its natural enemies for thousands of years, but was forced to give way to man's agencies such as destructive lumbering, repeated fires and grazing.

That forests follow forests, is an axiomatic truth known to all observers or students of nature, so we must look to the causes, other than the natural laws, for the decrease of the forest domain.

The forest tree as all other flowering plants, has its beginning in the seed so our knowledge of the origin and distribution of the present forest types must be built upon the foundation of a thorough knowledge of the seed.

From the maturity of the seed to the final establishment of the forest there are five principal points to consider, viz:

1. Seed Production, as to amount produced and the periodicity of the seed years.

2. Seed Distribution, agents and methods of distribution.

3. Germination, favorable and adverse conditions.

4. Establishment of the Seedlings, Ecological and Pathological factors involved.

5. Viability, conditions under which the seed will retain its vitality and length of time it will remain viable.

SEED PRODUCTION.

Production of seed is nature's method of perpetuating her species and she seems to have equalized the drawbacks one species may encounter by putting the other species with which it must compete under some other disadvantage. This appears to be true when some of the associated species such as the Yellow Pine and Lodge Pole Pine, or the Douglas Fir, Hemlock, Western Red Cedar, and Western White Pine are considered. The Yellow Pine has a much larger seed and consequently is better able to establish itself under more favorable conditions but the Lodge Pole Pine is a much heavier seeding tree and produces millions of seeds more than the Yellow Pine so what it loses in ability to contend with the unfavorable conditions it gains in having so many more seeds and consequently more seedlings with which to begin the struggle and the result is known to all who have seen these species in their native homes. The Lodge Pole Pine will usually get possession of the ground where a fire has destroyed the forest but the Yellow Pine will again gradually push it back if left undisturbed, although under favorable conditions the Lodge Pole will maintain possession of the ground, not because the site is unfavorable to the Yellow Pine, but because the Lodge Pole is there in sufficient quantities to successfully compete with the Yellow Pine.

This same condition is true with the Hemlock and its associates. If the enormous quantities of seed produced by the Hemlock annually, had the same chances of succeeding as the species with which its associates, as the Douglas Fir, Western White Pine and Larch, soon the entire forest would be Hemlock, but the larger seed of the White Pine and Douglas Fir make it possible for these seedlings to withstand the drought and compete more successfully with other species. The small seed of the Cedar is another example. Although there is enough Cedar seed produced annually to seed all of the area, the fact that the seed must have exceptionally good conditions for germination again limits this species and prevents it from getting entire possession of the ground.

These points are borne out by the fact that all trees producing larger seed invariably produce less seeds. The Sugar Pine produces only a fraction of the number of seeds produced by the Douglas Fir and the Douglas Fir again only a part of the number produced by the Hemlock. In the Lake States, the Jack Pine produces much more seed than the Eastern White Pine or the Norway Pine, and these species are always in keen competition with one another except in the most unfavorable localities where the Jack Pine gains possession of the ground.

The periodicity of seed years is too great a variation to use in any practical application for future work but must be considered in order to know when the last heavy crop of seed was produced.

Various methods for studying seed production have been proposed and tried, but all of them arrive at only a theoretical conclusion as to the production of seed per unit area and since the periodicity of the seed years is so variable, knowing the past years of seed production will not serve as an index when the next seed year will be. The heavier and lighter crops of seed are dependant upon the climatic conditions so they cannot be predicted, except by Hick's almanac. Nevertheless we know that the forest is producing seed, sometimes annually and sometimes at periods of two or three years or even more and it is sufficient to know for the purposes of management, whether the last crop was a sparse, medium, or heavy crop. The seed produced by the forest is annually, or whenever produced, falling upon the forest floor and there being covered by the falling needles, and the accumulation of vegetable matter, thus putting the seed under continually moist, cool conditions and storing it for the future.

In regard to seed production Darwin says: "Large numbers of seeds are destroyed. The greater chance against any given seed reaching a suitable locality and attaining maturity, the larger the number of seeds must the plant produce in order to maintain its numbers and as a general rule the smaller will the individual seeds be. On the contrary the greater the chance that each seed enjoys of arriving at maturity, the smaller the number of seeds that is necessary, and in such cases it is an advantage that the seeds should be large".

In any ordinary seed year the forest produces enough seed to produce a stand of seedlings so it is not the lack of production of seed that makes the forest unable to perpetuate itself and reclaim areas upon which it has been destroyed by its natural enemies, or through artificial means by man.

SEED DISTRIBUTION.

Seed distribution has always been a much discussed subject and a great many theories in regard to the migration of the forest have been held in the past and opinions vary a great deal at the present time as to causes of reproduction following large burns and areas from which the timber has been removed artificially.

Nature has provided nearly all of the seeds of the coniferous trees with wings and in this way provided for wind distribution so naturally, the idea that the seeds were distributed by the wind has been accepted and taken without considering the nature of the seed and its wing and the influence of the wind upon the seed as it leaves the cone in the top of the tree. Most of the seeds have the wings attached to one end of the seed and have the wing on one side only so in an ordinary wind of ten or twelve miles per hour the seed will begin a downward spiral whirl and land within two chains of the base of the tree. And since in a large part of our coniferous forests the autumn, or seeding time, is usually a time of little wind, the wind cannot be considered a factor in seed distribution only as influencing short distances from the seed-trees. To be sure the occassional blast of wind at the higher altitudes, blowing at the rate of seventy-five miles per hour, as has been measured by the writer in the Cascade Mountains of Washington, may carry an occassional seed for a long distance, but it will never produce stands over an area.

Water is a distributing agent among the moisture loving species and by carrying along the seed with the stream either by floating or by getting onto some moss or debris along the banks of the streams become covered with species that drop their seed into the stream.

Animals play a rather incidental part in seed distribution and the carrying of seed by birds may account for the occassional trees found in unexpected places. The most striking instance of animal distribution is seen in the Yellow Pine regions where the squirrels, chipmunks and mice collect and cache the seeds or cones. The squirrels and chipmunks gather the cones and cache them while the mice gather the seed only and store it away. Usually the caches are in piles under logs in stumps or other hidden places but often on the grassy slopes of the Yellow Pine region the squirrels store separate cones under the tufts of grass and I have examined and collected cones from caches that covered patches 200 feet square or more. The mice also cache small piles of pure seed under these grass tufts. Naturally not all of the cones or seed is again found by the rodents that store it and in this way they have become planters of seed even though they take a heavy toll for their work. This accounts for the patches of Yellow Pine reproduction on some of the grassy slopes of western Montana and Idaho. Tufts of Yellow Pine have been found containing 10 to 20 seedlings and upon digging them up the remains of the cone could be seen where it evidently had been cached by the rodent.

In studying seed distribution and seedling establishment the following methods were used:

Strips 8-1/4 feet wide were run 2-1/2 chains apart, thereby covering 5% of the total area and crossing it often enough to get representative areas under all conditions of moisture, shade, exposure (as to slope), and soil.

Maps, showing location of streams, timbered areas, seed-plots, burned and unburned slash areas, and topography were made.

Notes were taken on the kind of soil, whether silt, sandy, rocky, clay, etc., vegetative ground cover, condition of soil whether mineral or covered with humus, duff or litter, and amount of charred logs and slash on the ground. Number and age of each species of seedlings were recorded with conditions under which each individual or group of seedlings was found as to soil conditions and shade or protection by logs or slash.

Each chain was taken as a unit and written up separately. The strips were designated by the letters of the alphabet, and the chains in each strip by numerals.

The following is the report in detail of one of the areas studied:

Designation Kaniksu - Fidelity Lumber Co., March 18, 1907.

Location Sec. 26, T.57 N., R.5 W., Boise M.

Topography Rolling, traversed by Pine Creek - a non drivable stream - and the West Branch River - a drivable stream.

Slopes and ravines shown by map.

Soil Silt and sandy loam, dry, gravelly on hillsides.

Condition before cutting Forest mature and over-mature consisting of two age classes of 100 years and 200 years.

Considerable fungus and bug injury.

Reproduction Hemlock and Cedar heavy throughout.

White Pine and Larch in groups in openings.

Utilization All merchantable timber, living and dead, standing and down, cut.

Brush disposal All unmerchantable timber slashed and broadcast burned.

Burned-over June, 1910.

Seed Years Good seed crop in 1909 and a fair crop in 1911.

Silvicultural System Clear cut with seed plots, left.

CONDITIONS OF STAND BEFORE CUTTING

	White Pine	White Larch	Red Fir	Cedar	Cedar Poles
Average total height of trees	140'	140'	120'	120'	75'
Average diameter of trees	20.1"	20.4"	20.4"	27.0"	12.8"
Average number of trees per A.	27.4	3.7	0.8	2.8	17
Average stand feet b.m. per A.	17,564	2,068	358	2,496	545
Per cent of total stand	79	11	2.5	7.5	
Seedlings less than 5 feet high per acre per cent of stand	30	10	10	50	
Trees between 5 feet high and 6 inches D.B.H. per acre	10	2.5	2	16	
Number trees above 6 inches D.B.H. to be left	4.5	1.5	0.5	5.2	

Considerable Hemlock was scattered all through the stand, especially young growth of the pole, sapling and seedling stages, which was not taken into consideration in the above estimate.

PLATE NO. VII.

Showing the location of the strips as they were run and the topography of the area.

PLATE NO. VIII.

Showing the migration of the seed from the seed trees. This migration chart was made up by taking the number of seedlings per acre on each chain of each strip and getting the average for the first chain out of the timber and the second chain etc.

Ground Cover When Examined September 1912.

Scattering individuals of Wild Rose (Rosa), Bearberry (Arctostaphylos), Thimble Berry (Rubus), Solomon Seal (Polygonatum), Fern (Pteris), Fireweed (Epilobium), Mountain Maple (Acer), Willow (Salix), Service Berry (Amelanchier), Vetchling (Lathyrus), Thistle (Carduus), Horsetail (Equisetum), Lupine (Lupinus), Alder (Alnus), Goldenrod (Solidago), Spiraea, Lamb's Quarter (Chenopodium), various kinds of grasses in tufts and in heavy stands on river bottom flats and Clover (Trifolium) along the road sides making a ground cover of about 50 per cent but not an even cover as the vegetation is in groups with many open or sparsely covered areas.

The areas burned are quite free from any material left except some scattered charred logs. The mineral soil is exposed in many places and the remainder is covered with spots of humus and duff with strips of needle and wood litter along the timber where the fire did not run. The soil has been in excellent condition for reproduction since the burn of June 1910 and is still in good condition so the absence of reproduction is not due to soil conditions.

Along the West Branch river and the Pine Creek the low flat land is heavily covered with grasses and ferns which leaves these areas in unfavorable conditions for reproduction.

The cutting as a whole naturally divides itself into units which have similar factors influencing reproduction as seed-plots, slopes, slash etc.

Plate VII. shows the topography of the area and the position and direction of the strips run.

Plate VIII. -The Migration Chart, also shows the area divided into units having similar factors influencing reproduction. These areas are designated by the letters of the alphabet and in case any letter appears on two or more areas it indicates that these ~~are~~ areas are similar.

Areas A.B.C. and D. are all within seed plots under about 50 per cent shade with sparse annuals and ground cover of duff humus and litter. The seed trees in the plots are healthy except in C and in the edge of D where they have been badly damaged by fire. E is an area of unburned, partially piled slash on a steep north slope of 20 to 40 per cent with scattered small trees of Hemlock and Cedar. The ground cover is of sparse annuals and patches of humus, duff and litter. F. is an area of unburned, partially piled slash on a southeast slope of 15to 20 per cent. The ground cover consists of scattered annuals and a large per cent of the soil is covered with litter and duff. Scattered trees of Hemlock and small Cedar were left standing on this area. G is practically level. The greater part of it is unburned slash, partially piled and the northern part of it has a pole stand of Grand Fir and Cedar. The ground cover consists of a few annuals and litter and duff with some exposed places of mineral soil. H is a south and west slope of 10 to 40 per cent, very dry hot situation. The north half of this area is covered with unburned piled slash. Ground cover of scattering annuals and tufts of grass except along the West Branch River where there is a heavy cover as previously described. J is the general broadcast burned area of flat benches and slopes. The ground cover is described previously in the general description.

The migration chart shows that the reproduction is much heavier on all of the areas where the slash was left unburned. This is undoubtedly due to the seed and seedlings left on the ground at time of cutting as there are no seed trees in the near vicinity of areas E. F. and G. to re-seed them and all of the burned areas alongside of these areas had no reproduction on them. Areas E. F. and G. had seed trees of Cedar and Hemlock on them but no White Pine.

PLATE NO. IX.

Looking northeast over Fidelity cutting on Sec. 26.

Seed-plot B in center of view. Seed-plot A at left and seed-plot C at right with seed-plot D showing in background between B and C.

As shown by the migration chart the distance of seeding from the seed-trees seldom exceeds two chains to any appreciable amount.

The habitat of the seedlings found was generally similar to the conditions of the general area which indicates that no seed has been sown on the area farther than shown by the migration chart.

These points were borne out by all of the areas studied.

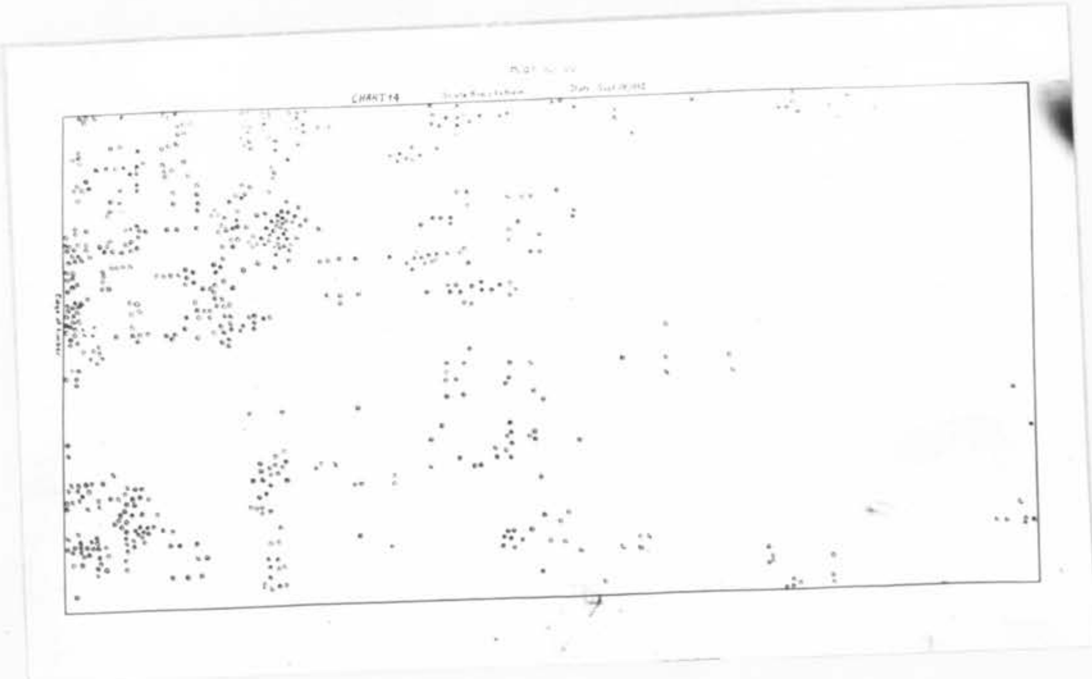

PLATE NO. X.

Showing the distribution of seedlings along the edge of the timber and distance of seeding from seed-trees. The seedlings are from 1 to 5 years old and all ages are distributed over the plot.

PLATE NO. XI.

Showing the timber beside the plot in Plate X. The seedlings on this plot are from seed produced by the trees shown here,; White Pine 1 to 5 years old in foreground; thrifty stand of seed-trees of White Pine, Cedar, Hemlock, Larch, Douglas Fir, and Grand Fir, in background. As seen here there is scarcely any ground cover to interfere with reproduction.

PLATE NO. X.

Size and Location - 1 ch. wide, along timber, by 2 chs. long, out from timber.

Aspect - 5 per cent East slope.

Soil - Deep silt soil, well drained.

Ground Cover - Scattering annuals and shrubs. Mineral soil exposed on a large part of the plot.

Direction from Seed-Trees - East.

Seed-Trees Within one Chain of Plot - 5 White Pines, 14 to 26 in. D.B.H., 1 Cedar 16 in D.B.H., 1 Hemlock 15 in. D.B.H., 2 Larches 16 and 26 in. D.B.H., 1 Douglas Fir 18 in. D.B.H., and 1 Grand Fir 18 in. D.B.H. All healthy and in good condition for producing seed.

Light Values, Under Which Reproduction is Coming in - Value of .05 readings taken one chain into timber where White Pine reproduction stopped.

This shows that the trees are seeding nearly every year but the distance of seeding is about the same every year. A large number of plots taken under varying conditions all showed the same results.

During the summer of 1913 an intensive study of a section located on the Yacolt burn of 1902 on the Columbia National Forest, was made by running strips 8-1/4 feet wide and two and one-half chains apart, over the entire section. This width strip was used because it is a multiple of a chain. The acre 5 chains long and 2 chains wide was taken as a unit, and by the above method each acre was crossed twice thus making a 5 per cent examination of the area covered. The age of all seedlings found on the strip was taken as well as the number,also the height of seedlings found on every third acre to get the development on the various slopes and exposures. Heights were taken in 4 inch classes. Notes on the soil conditions were taken and topography with an aneroid and abney.

The strip method gives the continuous conditions and shows the zonation of the different types better than the plot and since this study was primarily of migration it was necessary to follow the changing conditions closely.

After the study of the section was completed eight strips were run radiating out from the four corners and the four central points of the section in order to get the location of all green timber that would influence the seeding on the section studied. These strips were studied the same as the section. The strips were run out far enough to cover a township, that is 2-1/2 miles long from the sides and 3-1.2 miles long diagonally from the corners, comprising in all an area of 23,040 acres.

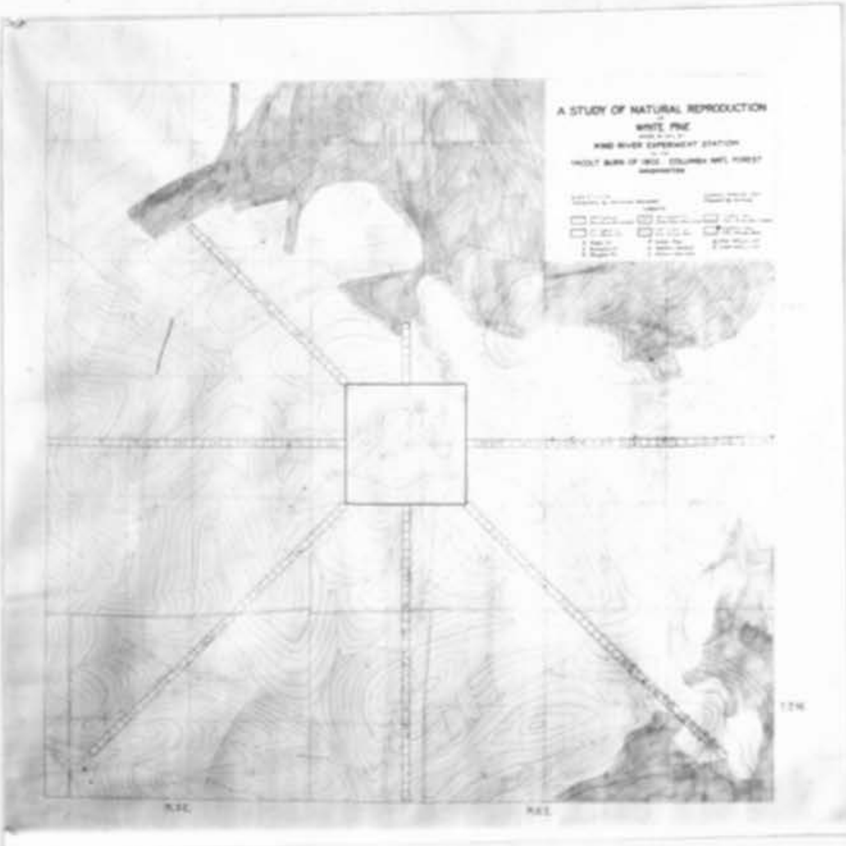

PLATE NO. XII.

Showing method of covering the township studied in the Yacolt burn on the Columbia National Forest. The section shown in the center was covered intensively as described before and the blocked lines radiating out from the section show the method of covering the township in the extensive work. Each block containing dots shown, covers six acres and the dots represent the reproduction, each dot indicating 100 seedlings per acre. This map shows the White Pine. Maps were made for each species. The dark portions of the map show the green timber left. This timber contains very little White Pine and none that is seeding out over the burned area, yet the above map shows very conclusively that the White Pine is evenly scattered over the entire burn regardless of location of seed trees.

The strips radiating out from the section are divided into blocks of six axres each but the legend indicates the number of seedlings per acre. The notes were taken the same as those of the intensive study of the section but averaged in blocks of six acres because the acre blocks were too small to record the legend. These strips were crossed with one line only.

The average of the heights of seedlings of all species on the different sites and situations showed that site quality and moisture were the controlling factors in the height growth of the seedlings. Slopes showed a decided difference in the height growth, sometimes varying 20 to 30 inches from the south slope to the north slope but the difference in growth could always be interpreted in terms of moisture as seen by the fact that the seedlings made just as good and even better growths on the south slopes where they were located near springs or any moist ravines. The different species did not show any marked differences in this respect except that the White Pine and Douglas Fir were able to establish themselves on drier and more exposed situations than the Noble Fir, Amabalis Fir and Hemlock.

The study showed that the reproduction occurs over the entire burn varying in density regardless of the location of seed-trees often being much more dense at a distance 2 or 3 miles from seed-trees than near by the trees, often reaching 20,000 to 30,000 seedlings per acre. The distance from the seed-trees and the erratic occurence of the seedlings in dense stands sometimes near seed-trees and sometimes at great distances from them showed that the seed was not being blown in by the wind. On the area studied, the Noble Fir was seeding a maximum distance of 10 chains, the Amabalis Fir 10 chains, Douglas Fir 20 chains, Hemlock 20 chains and in some instances perhaps farther, while no check could be taken on the Western White Pine because there were no seed-trees found that were producing seed and no young seedlings found. None of the species were seeding sufficient to produce stands more than 4 or 5 chains except Douglas Fir.

When this area was burned over in 1902 all of the timber was killed and the seed of the crop of 1902 badly scorched or burned as the fire went through in the early part of September. That there were no green trees left after the fire, is shown by the fact that there are no unburned cones or cone scales in the burned over areas while charred cones and cone scales as well as seeds of all of the species of the area were found. Also in places where the surface of the litter and duff was charred and undisturbed since the fire seeds were found still buried in the duff, some of them with perfect wings. These facts shecked with the appearance of the seedlings in stands of over 30,000 to the acre and ending in clear cut edges show that the seed was in the litter and duff and lived through the fire, a large percent of it germinating the first season as shown by the large percent of 11 year old seedlings. The 5 to 10 year age class shows the distribution of the seedlings that same from the seed which germinated some years after the fire and those ay great distances from the seed-trees undoubtedly came from the seed which had remained dormant in the litter or duff as there were no seedlings under 5 years old found in these localities and in the case of the Western White Pine there were no seedlings under 5 years found during the entire study although the White Pine seedlings were distributed over the entire area studied. This indicated that the White Pine seeds were viable for 6 years under the conditions they were exposed to. White Pine seeds were found in some of the charred cones and also some in the litter and duff, but these undoubtedly were killed by the fire or were not viable seeds.

The fire came from the southeast and the reproduction is invariably sparse on the south and southeast slopes where the fire was hottest and all of the litter and duff burned. On these slopes there are no patches of reproduction appearing and the occassional seedlings show that very little seed was left after the fire, while on the slopes not struck by the direct flames of the fire the reproduction appears in very dense stands regardless of the distance from the seed-trees.

As shown by the maps the reproduction is found at distances of 3 and 4 miles from the nearest seed-trees and as with the White Pine there are no seed-trees in the country that would have any influence on the area over which the reproduction of this species extends there can be no doubt that the seed was there after the fire passed over the area. This seed may have dropped from the trees the previous year or even earlier, as must be the case where these heavy stands of reproduction follow the fires the first season as the seed from one season would scarcely produce such dense stands. If the seed of the year the fire passed over the area was not killed, which is very doubtful, this study shows that even this seed must lie dormant for several years. The indications are that the White Pine remained 6 years, Douglas Fir 6 years, Noble Fir 3 years, Amabalis Fir 5 years, Hemlock 6 years and Yew was found scattered over the typical slopes of the species varying in age ffrom 11 years to 3 years showing that the seed remained dormant for 8 years. The yew was a good index in accounting for the seed on the area as there is no question about the wind distribution of the berry and although the theory that animals carry the seed may be true to a c ertain extent it is scarcely possible that the birds would take the pains to carry the seed back to the slopes best adapted to the species and among the old burned stumps of the stands of Yew before the fire.

These conditions are duplicated on all of the burns gone over on the Snoqualmie National Forest and the Oregon National Forest. The burns on the last named forests were not studied, but general observations indicated that the conditions were the same as those found on the Columbia, the noticeable feature being the universal failure of reproduction following a second fire over any area at any considerable distances from seed-trees. This fact shows that the seed did not come from any of the remaining green trees because if they had seeded the area the first time they would have re-seeded it after the second fire also.

PLATE NO. XIII.

A stand of Noble Fir and Amabalis Fir reproduction about 1 mile from seed-trees. Twenty-five thousand seedlings per acre. The significant feature shown in this view is the clear cut edge of the reproduction. Note how well defined the edge of the seedling growth is and none in the foreground or on the strip up to the large Noble Fir tree in the center. This is often found in different localities and can be explained only by the surface fire dying out along this line burning all of the litter and duff up th the point where it dies and the seed in the litter and duff left unburned germinating. This shows clearly that this seed was not blown in,also that no seed came here since the fire.

PLATE NO. XIV.

View on Yacolt burn of 1902, on the Columbia National Forest. Showing edge of the green timber at the extreme right of the view, no other green timber in sight. This is part of the township described before, where the reproduction study was made. Looking northwest from Lookout Mountain.

PLATE NO. XV.

View on Yacolt burn of 1902, on the Columbia National Forest, showing the condition of the timber and the ground after the fire. Note the bare ridge and the left hand side of the view (south slope) where the fire was hottest and the right hand side of the view (north slope) where the fire was not as hot on the ground, since the fire came from the southeast. The arrow points to the reproduction coming in on the north slope getting denser as it gets farther down the slope. This is usually the case with the reproduction, being denser on the north slopes where the fire was less severe.

PLATE NO. XVI.

View on Oregon National Forest showing the results of a second fire. This area was burned over in 1902 and followed by dense reproduction of Douglas Fir, Noble Fir, Hemlock and Cedar. The second fire ran through in 1909. Note the boundary of the second fire not followed by reproduction.

PLATE NO. XVII.

View on the Snoqualmie National Forest in Washington showing a burn 20 years old followed by a second fire 11 years later. The patches of reproduction left show where the second fire did not run. The second fire has not been followed by any reproduction.

GERMINATION OF SEED.

That the seedling is dependent on the food stored in the endosperm of the seed was shown by tests in sand, soil to which nutrient solutions had been added, and potting soil made up of leaf mold and sand. The following nutrient solution was used:

To each liter of water was added:

1.	gram	Calcium Nitrate
0.25	"	Potassium Chloride
0.25	"	Magnesium Sulphate
0.25	"	Acid Potassium Phosphate

The soil was moistened with this solution and always watered with the same solution whenever necessary.

The seeds germinated equally well under all of the conditions but the differences were very soon noticeable after germination.

Seedlings germinated in the sand came above the ground and appeared as good as those grown in the potting soil or in the nutrient solution until the seed-coats were shed when they began to fail and apparently were unable to get any nourishment or at least not sufficient to make a growth. After the cotyledon stage, these seedlings did not appear healthy and many of them soon developed their winter or resting buds while the ones in the potting soil and in the nutrient solutions made a good growth and did not develop any buds until they had passed through the regular growing period. Those grown in distilled water grew until the food of the seed was exhausted and then died.

Pinus ponderosa, Pseudotsuga taxifolia, Tsuga heterophylla, and Thuya plicata were the species of seeds used.

The following table shows the results of different depths of cover in average soil.

TABLE NO. VI.

Species	Depth of cover	Per cent germinated	Per cent appeared above ground.
Pinus ponderosa	1 in.	82	82
	2 in.	83	74
	3 in.	71	42
	4 in.	36	0
Pseudotsuga taxifolia	1/2 in.	93	93
	1 in.	87	85
	1-1/2 in.	72	64
	2 in.	67	50
	3 in.	42	3
	4 in.	17	0
Tsuga heterophylla	1/4 in.	96	96
	1/2 in.	92	76
	3/4 in.	86	50
	1 in.	64	5
	1-1/4 in.	42	0
Thuya plicata	1/8 in.	78	78
	1/4 in	64	52
	1/2 in	42	24
	3/4 in.	25	4
	1 in.	26	0
	1-1/2 in.	19	0

This table shows that seedlings will come up through the soil in direct proportion to the size of the seed and the development of the seedlings showed that the seedlings will grow to a size in direct proportion to the size of the seed without any nourishment other than that stored in the cotyledons of the seed. The fact that the seeds germinated even at the depths shown in this table and produced radicals sometimes 4 to 5 inches long, as was the case with the Yellow Pine, proves that the seedling must depend upon the food stored in the seed until it can produce chloryophyll bodies and manufacture its own food, and if it cannot reach the surface before its supply of nourishment in the seed is exhausted, it must die. On the other hand if it is able to get above the ground, even as a final effort, the cotyledons open up at once and turn green and the seedling gets a new source and supply of food.

It follows from this then that seed may often germinate when covered with litter and duff and the seedling not get to the surface but most of the seed covered in the forest floor is not under germinating conditions especially when covered to any depth since the forest floor is always cool due to shade and moisture.

The factors necessary for germination are moisture, aeriation, and temperature, and a seed will not germinate when any of these are wanting, temperature of course, meaning one favorable to the seed concerned which varies with different seeds.

The following experiments with the germination of the seed of Pinus monticola, Western White Pine, showed that the seed will stand some rigorous treatment and still germinate.

<u>Copper acatate</u> Five treatments varying from 4 ounces of Copper acatate to 1 gallon of water, to 32 ounces of Copper acetate per gallon of water in which the seed was soaked for 2 hours did not effect the germination. The germination was the same as in the untreated plot.

Six treatments with strengths of 2 to 4 ounces per gallon of water and soaked from 12 to 24 hours, showed no influence on the germination. Traces of blue coloring in the endosperm of all of the treated seeds showed that the acid had penetrated the seed coats. This coloring was quite noticeable in the stronger treatments but since some of the stronger treated plots gave as good germination as the untreated showed that the vitality of the seed was unimpaired. The seedlings that came up were thrifty and the root systems well developed.

Copper sulphate   Seed soaked for two hours in solution of 48 ounces of Copper sulphate to one gallon of water germinated 6 per cent. Soaked in 24 ounces of water to one gallon of water germinated 9 per cent. Eight treatments, varying from 2 ounces to 60 ounces of ~~xxxxx~~ Copper sulphate to a gallon of water soaked for two hours, failed to germinate. Ten treatments varying from one part Copper sulphate, by weight, to three parts water to one part Copper sulphate to 500 parts water, soaked for 2 hours, showed no influence on germination. Ten treatments varying from one part Copper sulphate to three parts water by weight, to one part Copper sulphate to 40 parts water, soaked for 2 hours showed no marked influence on the germination, but the seeds soaked in the stronger solutions were colored blue and most of them failed to germinate.

Zinc Chloride   Eight treatments varying from 2 ounces of Zinc chloride to one gallon of water to 60 ounces of Zinc chloride to one gallon of water, soaked for 2 hours did not have any influence on germination.

Four treatments from 12/32 to 1 ounce Zinc chloride to one gallon water, soaked for 30 minutes did not effect germination.

Ten treatments varying from 1 part Zinc chloride to 50 parts water, by weight, to one part Zinc chloride to 500 parts water and ten treatments varying from 1 part Zinc chloride to 3 parts water by weight, to 1 part Zinc chloride to 40 parts water, all showed no influence on the germination. Zinc chloride had been found to be a stimulant in germination in all of the work done in soil treatment for fungi and was expected to be a stimulant in germinating the White Pine seed but such did not prove to be the case.

Ether Seven treatments of ether varying from dipping to exposing the seed to the ether fumes for four hours showed that the seeds were killed if left in the fumes for more than one hour. Liquid ether was put into a bottle and the seed suspended above it on a gauze, thus subjecting the seed to the ether fumes. The bottle was closed with an air tight glass stopper.

Seed soaked in water Seed was put into water at the following temperature in degrees Fahrenheit and left for 40 hours: 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 212. The temperature of the water was 65 to 70 degrees F. when the seed was taken out. No germination was obtained above 150 degrees F. but the seed soaked in 140 degrees germinated 10 per cent as compared with 4 per cent in the unsoaked seed showing that the heat had stimulated the germination.

Sulphuric acid The following table shows the results of treatments of Western White Pine seed with Sulphuric acid.

TABLE NO. VII.

Plot number	Treatment of seed.	No. days before first germ.	Germ.% 15 days after 1st. germ. in series	Germ. % 50 days after planting	Condition of seed when planted
101 A	Dipped A	23	2.8	4.0	Pericarp charred by acid.
101 B	F-A-5	19	3.2	5.0	" " " "
101 C	F-A-10	26	1.6	3.2	Pericarp and mesocarp charred.
101 D	F-A-15	19	1.6	3.2	" " " "
101 E	F-A-30	23	1.2	3.0	" " " "
101 F	F-A-45	19	2.4	7.4	Pericarp nearly removed and mesocarp and endocarp charred.
101 G	Untreated	26	1.0	2.0	Normal.
101 H	Untreated	21	1.2	2.0	Normal.
101 J	1/2-A-30	21	1.6	3.2	Not discolored, seed-coats intact.
101 K	1/2-A-60	21	1.6	3.4	" " " " "
101 L	1/2-A-120	37	0.0	2.0	" " " " "
101 M	1/2-A-180	21	0.8	2.2	" " " " "

A=Commercial sulphuric acid
F-A-5=Seed soaked in acid, full strength for 5 minutes, etc.
1/2-A=One-half strength acid, that is equal parts with water.

The commercial sulphuric acid chars the seed-coats as soon as the seed is immersed in it and where the seed was left for 30 minutes and more in the full strength acid the seed-coats could all be removed by slightly rubbing the seed thus leaving the endosperm naked. Even in this state the viability of the seed was unimpaired and as the table shows the strongest treatment gave the best germination results.

Seed treated with half strength acid showed no appreciable effects of the treatment either in the direct effect upon the seeds or on the germination.

Germination of all the plots was perfectly normal, the seedlings in all the different treatments appearing in a healthy and thrifty condition except that the seedlings in the plots treated with the full strength acid for the longer periods appeared bringing practically nothing but the endosperm above ground in place of the seed and in some cases the cotyledons grew out through the sides of the endosperm as shown in Plate No. XVIII. Seedlings appearing in this way produced strong vigorous plants however.

Seed soaked in C.P.Sulphuric acid for 1 hour then the acid poured off and the seed covered with water. The reaction of the water and Sulphuric acid caused temperature to raise to 168 degrees F. and after it had been left 15 minutes the temperature was 120 degrees F. The pericarp was charred and most of it destroyed by the acid and the mesocarp and endocarp were also charred so they rubbed off easily, but the endosperm or food material of the seed was apparently uninjured. Some of the seed germinated. Seed soaked for more than one hour and treated with water failed to germinate.

PLATE NO. XVIII.

Seedlings germinated from seed treated with Commercial and C.P. Sulphuric acid. Note the absence of seed coats and the seedlings on the right with the cotyledons pushing out through the endosperm instead of shedding the seed-coat in the regular way. The seed-coats were so completely cut away by the acid that they were never brought above the ground.

The following chemical experiments to determine influence on germination were done with the Pinus ponderosa, Western Yellow Pine.

Copper sulphate   Ten treatments varying from 1 part Copper sulphate to 1 part water by weight, to 1 part Copper sulphate to 5-1/2 parts water showed that germination was stimulated by the chemical, and the seed-coats opened in a few days, but as soon as the seed-coats separated the Copper sulphate solution entered the seeds and stained them blue also killing the germinating seeds as soon as the tip of the radical appeared.

Copper acetate   Ten treatments varying from 1 part Copper acetate to 1 part water by weight, to 1 part Copper acetate to 5-1/2 parts water showed that germination was stimulated but the Copper acetate killed the growing tips as soon as they appeared. Chemical injury occured in all of the strengths. In the weaker treatments the germinating tips were stained blue and in the stronger treatments the entire endosperm and plumule were stained blue.

All of the above experiments show that the seed in the dormant state will withstand very severe conditions and the chemical condition of the forest floor, has very little influence on the viability of the seed, although it may be a major factor in the germination and development of the seedling. This however is another problem since the forest floor is always under very different conditions after a fire or cutting.

ESTABLISHMENT OF SEEDLINGS

In order to account for the present distribution of the forest species and the types within the forest, it is necessary to know under what conditions the seedlings of these species are able to establish themselves. When the seedlings or trees of any species are found on any site shows that that particular site is favorable to the species found there but it does not show that any other species would not establish itself there or develop there if given a chance. Sometimes it is merely a question of which species happened to get possession of the area after the virgin forest was removed or which species first had the opportunity of migrating there, while in other instances it is clearly a matter of competition or ability to withstand the conditions of the site involved.

Soil temperature, soil moisture, aeration, and light are the ecological factors which determine the establishment of a forest and determine the types within the forest and a large variation of any one of these factors on different sites does not mean that wide varying factor is the one which determines the type, since other factors varying less, but approaching nearer the limit of favorable conditions would have a greater influence on the establishment of the seedling or on the germination of the seed. All of the factors must be taken into consideration and also the limits of each under which the seedlings will grow. While the soil moisture may be equal in two different localities, the soil texture may have a decided influence in the availability of the moisture to the plants, that is there would be a decided difference in the wilting coefficient. Schant and Briggs have shown that all plants have the same ability to get water from the soil so this difference would not influence the types in these areas if the soil moisture was the same at all depths but the fact that the surface soil often dries out while the soil at a depth of six inches will be moist on protected slopes and dry on exposed slopes gives a decided advantage to the seedlings with a deep root formed early in its development. It is this fact that gives the Yellow Pine the advantage over the Hemlock and its associates in the forests of western Montana and Idaho, and for the same reason the Douglas Fir is able to establish itself on the drier slopes of the Cascades, while the Hemlock and Cedar fails. A south slope covered with Yellow Pine or Douglas Fir, and the north slope covered with Hemlock, White Pine, Cedar and other species, does not mean that each of these species is in its optimum habitat but is a question of competition and establishment. The Yellow Pine would produce even a better forest on some of the slopes occupied by the other species if it could establish itself there, but it is crowded out by the large number of seedlings of the other species while on the other hand the Hemlock and Cedar do very well under the conditions of the south slope wherever they can get sufficient moisture to establish themselves. The reason these species are not mixed all through the forest is not due to the lack of seeding or even the germination of the seeds on the different slopes. This has been found to be the case by the writer where the two types met on a ridge. The south slope was seeded with the seed of the species found on the north slope and the seedlings of the Hemlock and Cedar and Larch were found germinating along with those of the Douglas Fir and Yellow Pine in the spring but when examined in the fall only some of the seedlings of the Yellow Pine and the Douglas Fir were left because the small seedlings of the other species were unable to live through the dry period of the summer due to their small roots and inability to reach the moist layer of soil below the dry surface. These conditions are repeated year after year and still the types remain the same. It is very noticeable wherever a ravine or spring keeps the south slope moist the species of the north slope are found. Evaporation is one of the chief factors in the establishment of the seedlings for the different slopes often get about the same amount of precipitation but there is such a marked difference in the evaporation that the exposed slopes dry out while the north and protected slopes remain moist. This is shown in table No. X.

The conditions under which the seedlings became established were also studied when the migration study was made on the area shown in Plate No. VII. The results of this study are given in the following table:

TABLE NO. VIII.

CONDITIONS UNDER WHICH SEEDLINGS WERE FOUND

	White Pine	Cedar	Hemlock	Larch
SOIL				
On Humus	2%	1%	2%	
" Duff	30%	6%	24%	63%
" Wood Litter	35%	11%	33%	7%
" Mineral Soil	33%	82%	41%	30%
PROTECTION				
In Shade	44%	69%	54%	37%
Under Logs	6%	2%	7%	5%
In Open	50%	29%	39%	58%
AGE				
1 Year Old	43%	87%	81%	48%
2 Years Old	25%	12%	7%	18%
3 Years Old	27%	1%	10%	28%
4 Years Old	5%		2%	6%

These conditions were studied on all of the areas, and are summarized in the following table:

TABLE NO. IX.

CONDITIONS UNDER WHICH SEEDLINGS WERE FOUND

AVERAGE OF ALL THE AREAS

	White Pine	Cedar	Hemlock	Larch	Grand Fir
SOIL					
On Humus	3%	2%	7%	1%	9%
" Duff	34%	16%	19%	32%	28%
" Wood Litter	25%	22%	58%	17%	8%
" Mineral Soil	38%	60%	16%	50%	55%
PROTECTION					
In Shade	21%	54%	64%	82%	15%
Under Logs	8%	4%	8%	8%	25%
In Open	71%	42%	28%	70%	60%
AGE					
1 Year Old	37%	74%	87%	25%	2%
2 Years Old	19%	9%	8%	11%	4%
3 Years Old	34%	16%	4%	55%	35%
4 Years Old	9%	1%	1%	9%	50%
5 Years Old	1%				9%

In regard to the areas examined, the above tabulation shows that the White Pine seedlings start about equally well on the duff, wood-litter and mineral soil, but as shown previously the seedlings on the mineral soil are better established, due to a better root system. The small per cent on humus is due to the lack of the humus covered soil. The seedlings apparently need little or no protection. The Cedar and Hemlock were found in the shaded places where moisture is plentiful. The Cedar preferring the mineral soil and the Hemlock the wood-litter, usually starting on the old decayed logs where they are shaded and kept moist. The table is self explanatory as to the conditions under which the different species were found.

Under average conditions it is apparent that moisture is the chief factor which enables the seedling to establish itself.

The loss of many of the seedlings germinating in the shade is pathological and due to the shading only indirectly because the shaded moist conditions favor the development of the damping-off fungi, usually Pythium debaryanum. This may account for more of the seedlings being found in the open and not necessarily mean that the species studied will not develop under more shade.

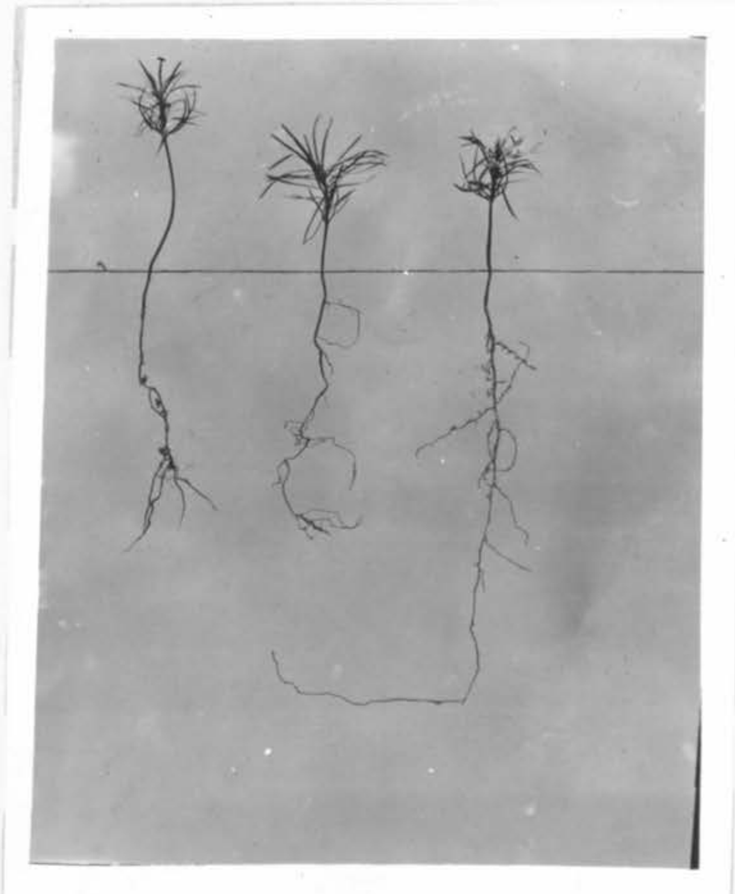

PLATE NO. XIX.

Shows top and root development of Western White Pine seedlings grown under different conditions (a) two year old seedling grown on duff, single root pushing its way down through the duff until it reached the mineral soil where it developed laterals as shown; (b) two year old seedling grown on wood litter showing the way the growing root tip follows the crevices back and forth between the annual rings and developes laterals to follow the moisture between the rings; (c) two year old seedling grown on mineral soil showing the long tap root developed to seek the deeper moisture. All of these seedlings were grown without protection or shade and the difference in top development is apparently due to the varying amounts of moisture available at the different periods of their growth. The seedling grown in the mineral soil forming a shorter, sturdier top and establishing a deeper and more permanent root system, while the others having more available moisture near the surface developed larger tops and smaller root systems. Measurements of the seedlings vary as follows:

	Top	Root
(a)	2.2 in.	3.0 in.
(b)	1.6 "	3.2 "
(c)	1.4 "	6.8 "

It is apparent that the seedling grown on the mineral soil is best established and prepared for any drought or unfavorable conditions.

(d) Shows the ground line of all three.

Many seedlings found under these conditions were dug and these taken as typical examples.

The following experiments are all located on Warren's Hill, Warren's Gap, and Pilot Knob near the Wind River Experiment Station on the Columbia National Forest. The meteorological factors influencing the results of these experiments were studied by taking readings every Saturday, from the middle of April 1913 to the first of November 1913, of the percent of soil moisture at the surface, at a depth of 6 inches and 12 inches, soil temperature at surface, at depth of 6 inches and 12 inches, evaporation from water surface (by having open water tank at each site), air temperature, Relative humidity of air, maximum and minimum temperatures of surface soil for the past week by having maximum and minimum thermometers set in surface soil at each site. These readings were taken on three sites, one on an exposed south slope at an elevation of 2,150 feet, one on north slope elevation 1,750 feet, and one on an intermediate flat with an elevation of 1, 150 feet.

In the spring of 1913, 100 seed spots of Douglas fir were sown on each of the sites, south slope, north slope, and flat, and 25 per cent of the spots were protected by wire cones on each site.

Three examinations were made. At the end of the season the seed spots on the south slope had no seedlings, either in the protected or unprotected spots, since all that germinated during the season died in the dry part of the summer. On the north slope the protected spots had an average of .69 seedlings per spot, and 44 per cent of the spots contained seedlings, while the unprotected spots averaged .25 seedlings per spot, and 22 per cent of the spots had seedlings. On the north slope there was no loss of the total number germinated. On the flat the protected seed spots averaged 2.85 seedlings per spot and 88 per cent of the spots had seedlings, while the unprotected spots averaged .31 seedlings per spot and 34 per cent of the spots contained seedlings. The loss of the total germination on the flat was 6 per cent.

In the spring of 1913 the following species were sown under wire screens on each site: Douglas fir, noble fir, western white pine, and western yellow pine. An area of about 16 square feet was sown to each species, one-half of the area being put in as a regular seed spot and the other half broadcasted without preparing the soil.

All of the sowing failed on the south slope, and the seedlings that germinated all died during the dry season. The noble fir did remarkably well on the north slope, and the Douglas fir and white pine did fairly well but the yellow pine failed. There was no loss of the total number germinated.

On the flat the Douglas fir did very well and had a 15 per cent loss of the total germination. The noble fir did fairly well, with a loss of 30 per cent of total germination, the white pine germinated very little and had a loss of 46 per cent of total germination, while the yellow pine germinated very little and 15 per cent of the total germination died.

TABLE NO. X.

TABULATION OF READINGS TAKEN ON PILOT KNOB, WARREN'S HILL AND WARREN'S GAP.
Readings averaged by months.

		April	May	June	July	August	September	October
Maximum temperature surface soil,								
	South slope		82.0	113.0	109.2	129.4	101.5	79.5
	North slope		71.0	81.5	77.2	82.4	63.5	61.7
	Flat		80.0	109.5	117.5	139.2	93.0	69.5
Minimum temperature surface soil,								
	South slope		37.0	46.0	48.2	46.8	43.2	38.2
	North slope		38.0	48.7	52.5	51.0	44.0	37.5
	Flat		37.0	47.7	47.8	45.0	38.2	33.7
Set maximum temperature surface,								
	South slope	46.0	59.2	63.2	90.0	121.0	71.7	56.2
	North slope	46.0	56.2	63.2	69.2	68.8	54.5	50.4
	Flat	44.0	60.0	69.7	92.2	104.6	75.7	56.5
Soil temperature 6 inches deep,								
	South slope	45.0	51.6	60.5	67.5	73.4	60.5	52.2
	North slope	43.0	49.7	58.6	61.2	63.4	53.2	50.0
	Flat	45.0	54.4	62.7	68.2	72.4	55.9	49.0
Soil temperature 12 inches deep								
	South slope	44.5	50.9	59.2	63.2	69.2	60.7	52.6
	North slope	42.0	49.0	57.5	59.0	61.4	53.7	48.7
	Flat	44.5	51.9	60.5	64.7	67.6	56.2	50.0
Air temperature								
	South slope	43.0	60.0	55.0	79.0	82.0	68.0	52.7
	North slope	46.0	62.0	61.0	75.0	76.0	64.0	51.5
	Flat	44.0	62.0	62.0	80.0	84.0	72.0	55.2
Relative humidity,								
	South slope		63.2	81.7	41.5	35.7	43.7	74.2
	North slope		68.4	75.5	45.2	42.6	52.5	75.0
	Flat		64.6	75.7	32.5	30.8	41.0	68.0
Evaporation from water surface in inches,								
	South slope		4.2	4.9	4.4	15.1	4.0	2.7
	North slope		2.0	1.6	0.9	1.8	0.7	0.9
	Flat		3.4	3.8	3.0	6.0	2.4	1.3
Per cent of water content in surface soil,								
	South slope	31.8	22.7	22.2	9.9	1.0	24.8	25.6
	North slope	29.1	29.8	23.2	15.3	6.5	27.4	35.3
	Flat	23.3	29.3	35.5	15.9	2.3	31.1	30.6
Per cent water content in soil 6 inches deep,								
	South slope	30.5	27.4	21.2	18.9	11.2	28.7	30.5
	North slope	35.9	23.1	25.9	23.2	17.5	26.8	32.1
	Flat	26.3	28.9	25.7	24.0	17.4	29.4	30.2
Per cent water content in soil 12 inches deep,								
	South slope	31.5	25.9	19.3	21.1	10.4	27.6	31.8
	North slope	27.5	26.0	26.7	23.0	19.4	18.9	32.1
	Flat	28.4	25.1	26.2	23.4	21.1	30.2	30.7

In order to determine the relative hardiness of various ages and classes of Douglas fir stock on different sites, and situations, seven different age classes of stock were planted on each site in the spring of 1913. Two examinations were made, one in June to determine how the stock had established itself, and one in October to determine how the plants came through the dry period of the summer.

The following table gives the results of the last examination:

TABLE NO. XI.

Kind of Stock	Situation	Per Cent Dead In Shade	Per Cent Dead In Open	Average Growth in 1913
1-0 Spring*	South Slope	9	43	1.3
"	North "	0	0	.9
"	Flat	10	12-	.9
1-0 Spring	South Slope	7	51	1.5
" "	North "	4	2	1.0
" "	Flat	8	18	1.3
1-0 Fall	South Slope	15	42	1.6
" "	North "	8	1	1.3
" "	Flat	1	17	1.3
½-½ Fall	South Slope	4	22	1.4
	North "	0	1	1.3
	Flat	2	4	2.0
2-0 Spring	South Slope	6	20	1.3
	North "	2	1	1.7
	Flat	1	3	2.3
1-1 Spring	South Slope	1	34	1.6
	North "	2	1	1.9
	Flat	0	0	2.2
1-1 Fall	South Slope	4	4	1.8
	North "	0	0	2.5
	Flat	0	0	2.5

* Seed from Eastern Washington,
All other seed from Western Washington.

It is very noticeable that the stock on the south slope needs some protection as shown by the large percent dead of those planted in the open.

The young stock which survived on the south slope made a better growth than on any other site due perhaps to a warmer location.

CONCLUSIONS.

Direct seeding by all methods is a failure on south slopes and only a partial success on notth slopes.

(a) Due to damage done by rodents.

(b) Due to heavy loss of seedlings by drought during the first season on south slopes and any exposed place.

Planting 1-0 stock is unsuccessful on exposed south slopes, and only fairly successful on other areas except north slopes where it is very successful.

All planting stock does best under protection of some bushes on exposed south slopes.

All methods of planting done reasonably carefully are equally successful in average or good localities when 1-1 stock is used.

2-0 stock is as successful as 1-1 stock under average conditions.

An area was selected where the ground cover of wild pea vine and brush was dense and one square rod was denuded of all vegetation and the area beside it left untouched. Readings of air temperature at the height of the crowns of seedlings, soil temperature at surface, 6 inches deep, and 12 inches deep, and soil moisture at surface, 6 inches deep, and 12 inches deep were taken each week on the denuded area and in the adjoining area where the natural vegetative ground cover was undisturbed. The object was to find the influence of ground cover following a burn or clearing. The results are summed up in the following table:

TABLE NO. XII.

NATURAL COVER AND DENUDED AREAS

	May	June	July	Aug.	Sept.	Oct.
Air temperature*						
Natural cover	60.8	59.2	70.7	86.6	72.0	55.7
Denuded	72.2	64.4	84.7	102.8	76.2	60.0
Soil temperature						
Natural cover, surface	55.6	56.0	62.7	73.4	63.5	56.2
" " 6 inches deep	52.2	55.2	60.5	68.4	61.0	54.5
" " 12 inches deep	50.9	55.0	60.0	66.4	60.6	54.5
Denuded, surface	74.5	67.5	92.5	124.2	89.2	64.5
" 6 inches deep	57.8	62.0	68.0	78.7	67.0	54.2
" 12 inches deep	56.3	61.5	67.0	74.4	66.2	56.2
Per cent soil moisture content						
Natural cover, surface	33.3	32.4	23.1	10.5	33.4	36.5
" " 6 inches deep	21.3	26.7	20.0	12.9	29.5	26.5
" " 12 inches deep	23.9	20.5	18.6	15.4	28.4	27.7
Denuded, surface	11.0	10.2	4.1	1.0	12.7	18.4
" 6 inches deep	26.7	24.1	22.5	17.5	24.2	29.0
" 12 inches deep	23.2	25.7	21.1	19.8	27.2	29.2

*Air temperature taken at crown on one-year old seedlings.

The foregoing table shows clearly the effect of evaporation from surface soil when denuded, also the greater per cent of soil moisture at the 6 inch and 12 inch depths as compared with these same depths in the area having the natural ground cover of wild pea vine and brush. Although the surface dired out on the denuded area the 6 inch and 12 inch still contained more moisture than in the area of the natural cover due to the moisture being taken out of the soil by the roots and evaporated from the leaves.

The hot dry surface soil accounts for the loss of one-year old seedlings on these exposed slopes, while the moist, cooler surface under vegetative cover gives the young seedlings protection. The greater amount of moisture in the 6 inch and 12 inch depths on the denuded area also shows why sturdy, large stock will succeed on such slopes.

PLATE NO. XX.

View of Natural cover and Denuded areas on which the above readings were taken. This shows the heavy cover of wild pea vine (Lathryus sp.) on the natural growth. This growth was removed from the denuded area in the early spring. Burned over in 1902.

The following Plates show the germination and establishment of various types and species of Conifers. As has been mentioned before, the size of the seed influences to a large extent, the development of the seedling. This is noticeable in these plates.

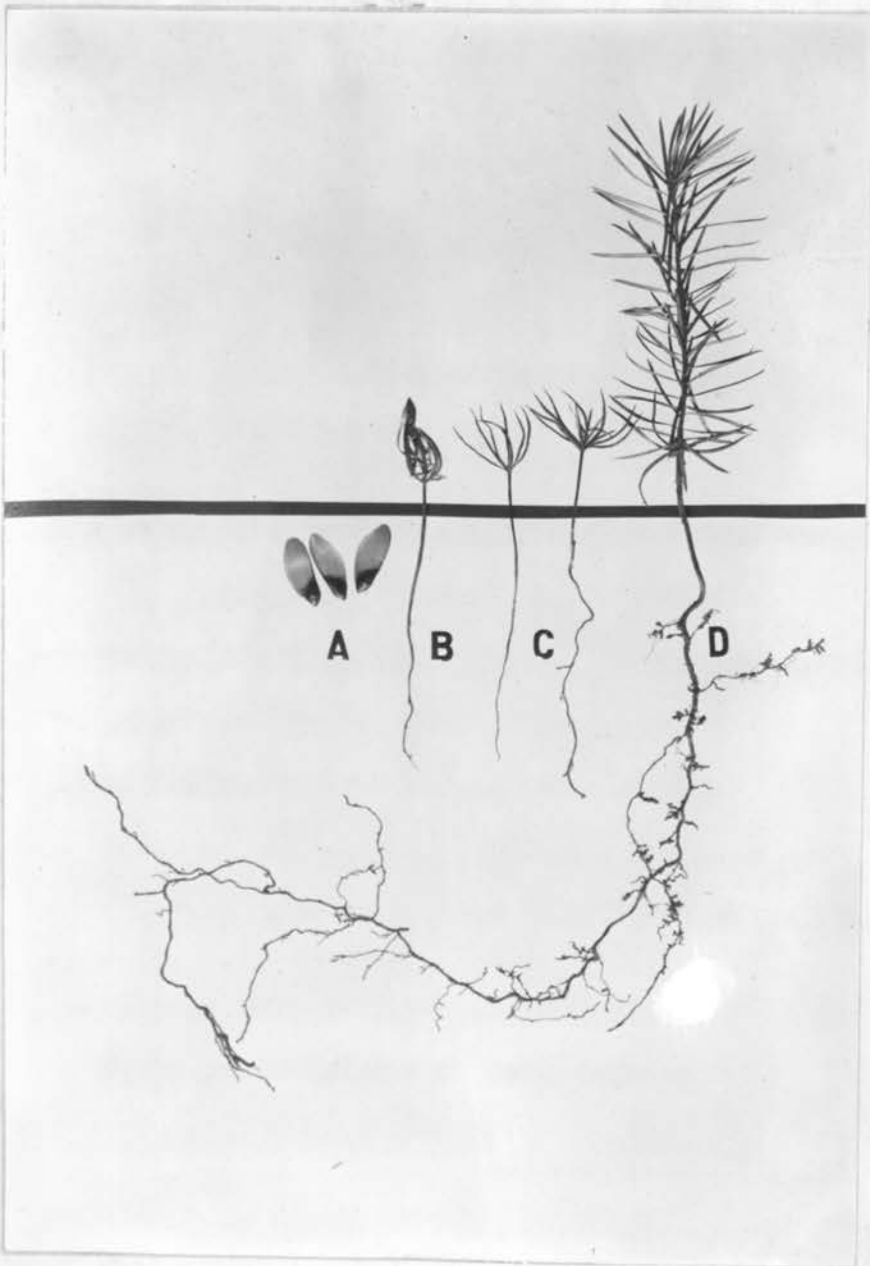

PLATE NO. XXI.

PSEUDOTSUGA TAXIFOLIA

DOUGLAS FIR.

(Size 2/3)

PLATE NO. XXI.

Pseudotsuga Taxifolia Size 2/3

Douglas Fir.

A. Seed, Color: Light reddish to a dark brown and lustrous above, pale white mottled with brown below, smooth

Size: 4-6 mm. long; 2-1/2 - 4 mm. wide at widest part, tapering to a point opposite wing. Wings dark brown, 6-8 mm. long, 3-4 mm. wide at widest part just below the middle, tapering to a rounding apex.

Weight: Average 35,000 seeds per pound.

B. Seedling as it Appears Above Ground, about to Shed Seed-Coat.

Hypocotyl green to reddish tinge, cotyledons green.

C. Seedlings with Cotyledons; green.

Cotyledons 1-1/2 - 2-1/2 cm. long; linear tapering point; 6-9 in number.

D. Seedling one Year Old.

Showing remarkable root system adapting it to the drier slopes and causing unusually fast growth.

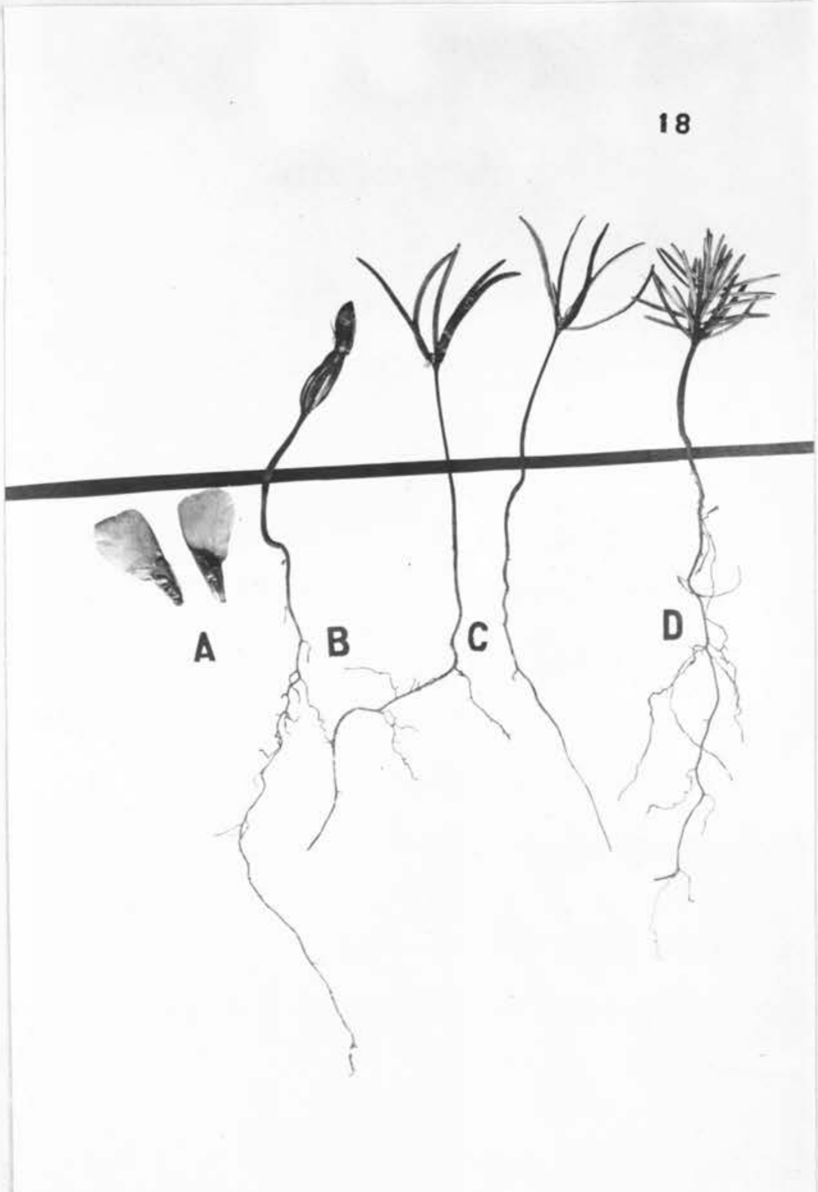

PLATE NO. XXII.

ABIES NOBILIS

Nōble Fir.
(Size 1/2)

PLATE NO. XXII.

Abies Nobilis Size 1/2

Noble Fir.

A. Seed. Color: Pale reddish brown, slight tendency to be glossy. Wing very slightly lighter brown than the seed.

Size: 10-12 mm. long, 5-6 mm. wide at widest part near wing. Tapering to point. Wing 10-15 mm. long, 12 - 15 mm. wide with widest part at top and forming a triangular shape with seed. Top almost trimcate.

Weight: 25,000 per pound.

B. Seedling as it Appears Above Ground, about Ready to shed Seed-Coat.

Hypocotyl reddish green. Cotyledons green.

C. Seedlings in Cotyledon Stage.

Cotyledons 2-3 cm. long, 4-7 in number, usually 5. Long slender, tapering point.

D. One Year Old Seedling. A well developed plant.

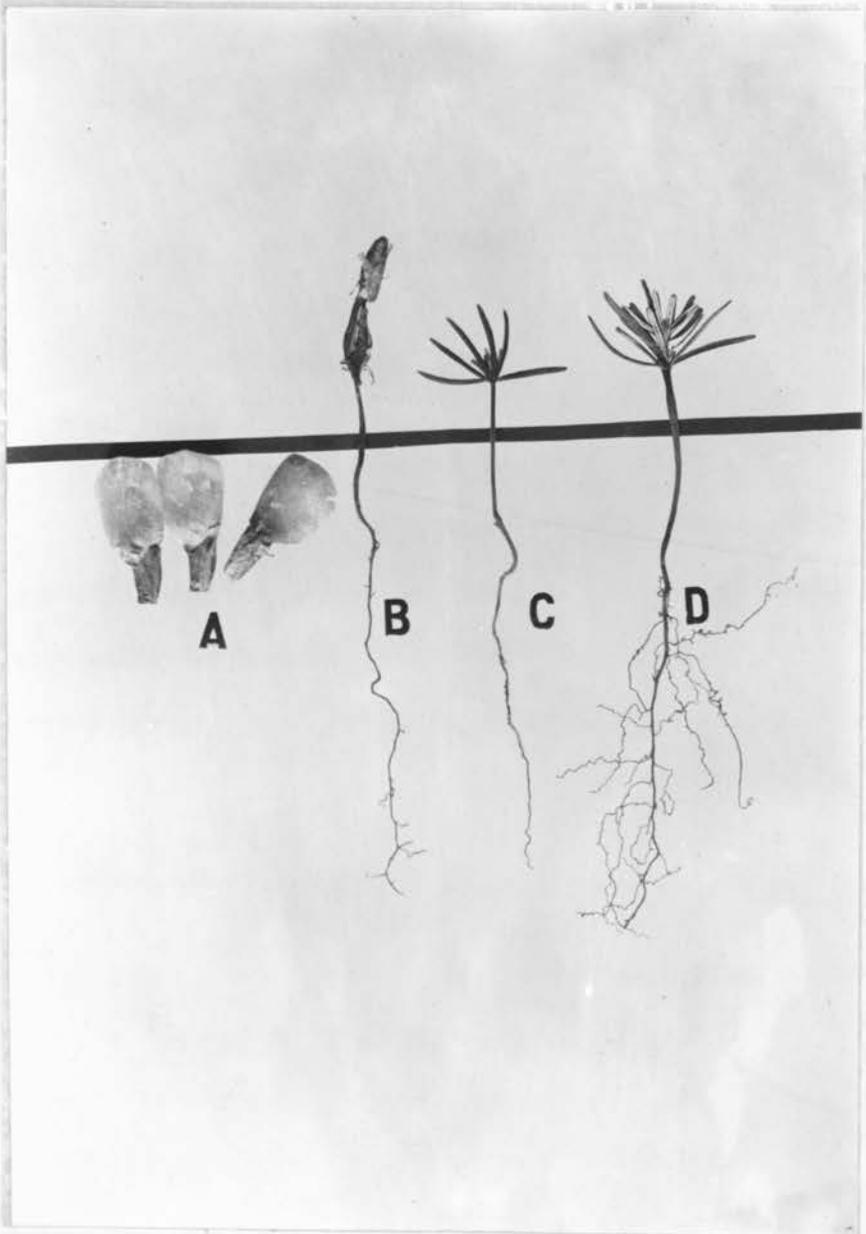

PLATE NO. XXIII.

ABIES AMABALIS

Lovely Fir.
(Size 4/5)

PLATE NO. XXIII.

Abies Amabalis   Size 4/5

Lovely Fir.

A. Seed, Color: Light glossy brown. Wings light brown.

Size: 1-1.3 cm. long, 4-5 mm. wide, broadest near top with square base.

Wings 1.4 - 1.8 cm. long, 1.2 - 1.5 cm. wide near top.

Broadest near top with slightly rounded apex.

Weight: 30,000 per pound.

B. Seedling as it Appears Above Ground, about to shed Seed-Coat.

C. Seedling with Cotyledons.

Cotyledons 1.5 - 2 cm. long, linear with retuse apex. This notch in the end of the cotyledon is a characteristic which distinguishes it from the other firs. Cotyledons green above and greyish below.

D. Seedling One Year Old, Showing that it is rather slow in establishing itself.

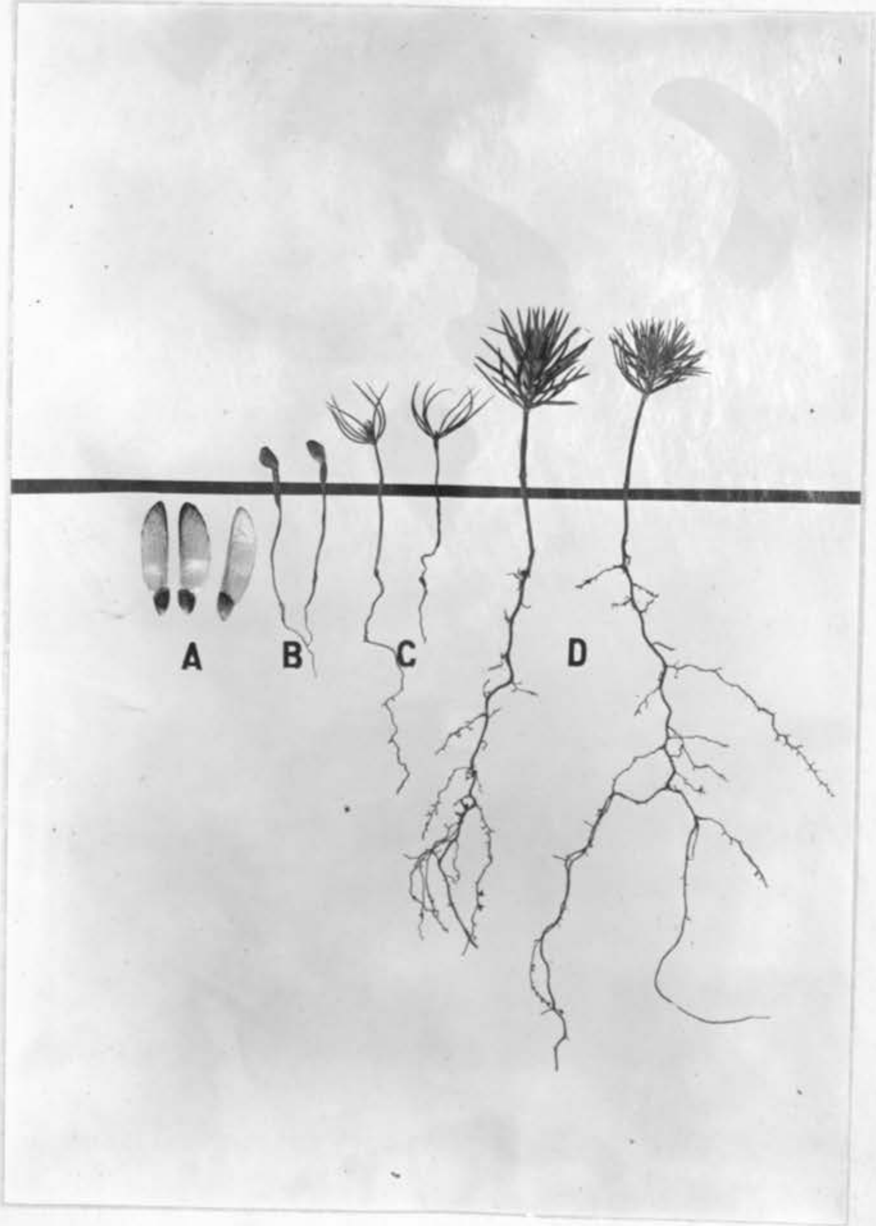

PLATE NO. XXIV.

PINUS MONTICOLA

Western White Pine.
(Size 2/3)

PLATE NO. XXIV.

Pinus Monticola Size 2/3

Western White Pine.

A. Seed, Color: Pale reddish brown, mottled with black.

Size: 5-7 mm. long, 4-5 mm. wide at widest part; oblong to triangular in shape. Wings light brown, 1-1/2 - 2-1/2 cm. long, 5-7 mm. wide at widest point, just above the middle. Rapid taper from widest point to a rounded apex.

Weight: Average 30,000 seeds per pound.

B. Seedling as it Appears Above Ground; green-sometimes pinkish, about to shed seed-coat.

C. Seedling with Cotyledons.

Cotyledons a cm. long, 6-9 in number; tapering point.

D. Seedlings One Year Old, Showing strong root system enabling the seedling to establish itself.

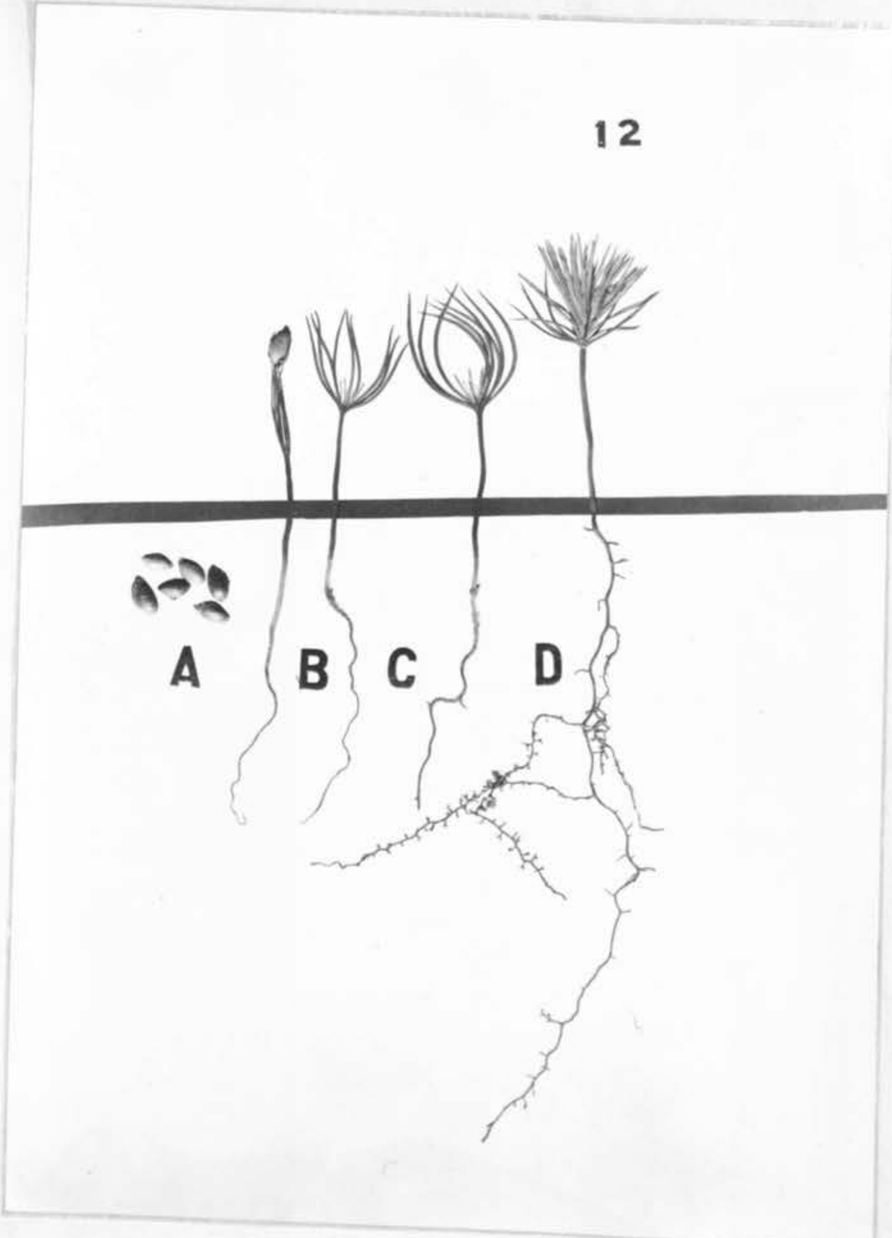

PLATE NO. XXV.

PINUS STROBUS

Eastern White Pine.
(Size 5/6)

PLATE NO. XXV.

PINUS STROBUS   Size 5/6

Eastern White Pine.

A. Seed, Color: Reddish brown, sometimes lighter brown mottled with black. Wings dark brown.

Size: 5-6 mm. long, 3-4 mm. wide at widest part, oval to triangular shaped. Wings 1 - 1.5 cm. long, 5 - 6 mm. wide just above seed and tapering gradually to an almost pointed apex.

Weight: 35,000 per pound.

B. Seedling as it Appears Above Ground, about to Shed Seed-Coat.

C. Seedlings with Cotyledons.

Stem pinkish green. Cotyledons 1.2 - 2 cm. long, linear with tapering point.

D. Seedling One Year Old. True leaves do not appear until second year. Seedling well established at end of first season.

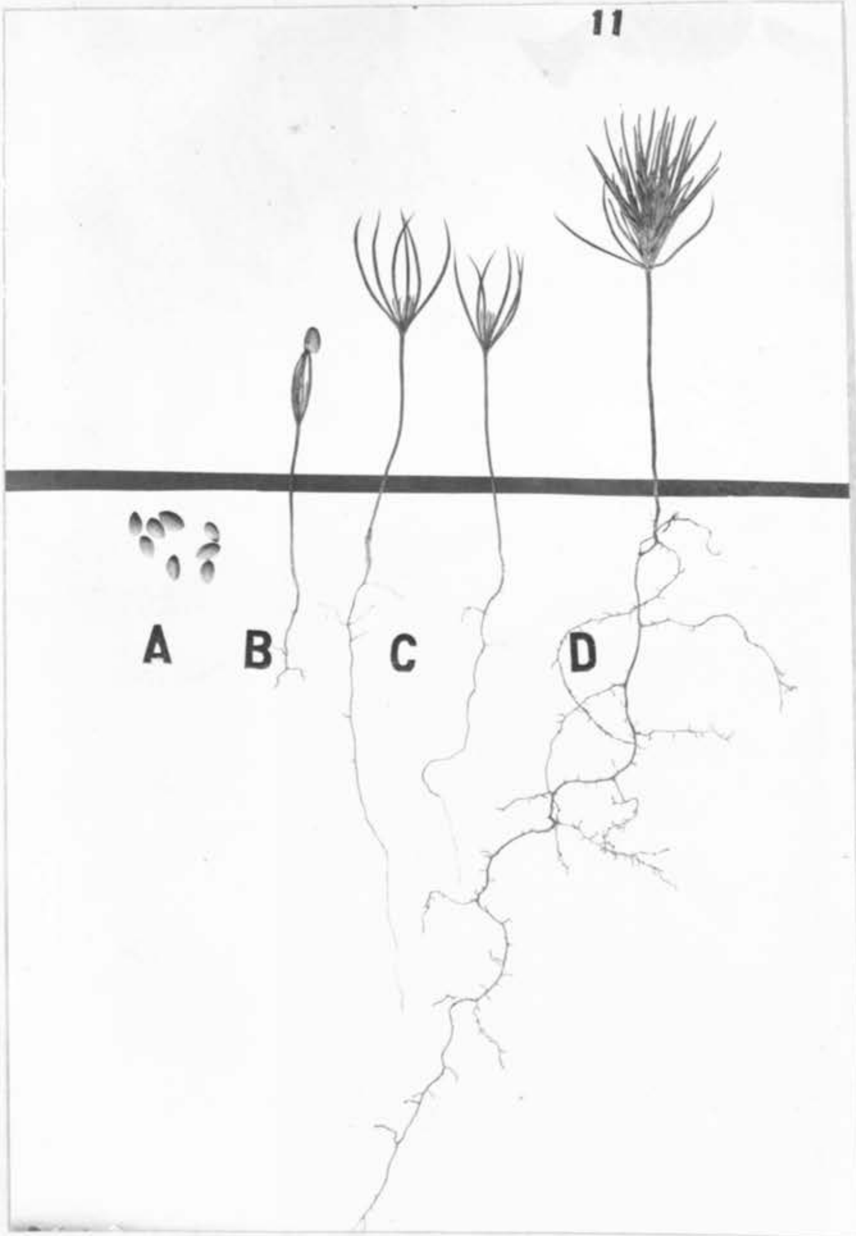

PLATE NO. XXVI.

PINUS RESINOSA

Norway Pine.
(Size 3.4)

PLATE NO. XXVI.

PINUS RESINOSA Size 3/4

Norway Pine.

A. Seed, Color: Dull chestnut brown, mottled with grey. Wings lighter brown with strips of darker brown.

Size: 4-5 mm. long, 2.5 - 3 mm. wide, almost round and oblong. Wings 1 - 1.5 cm. long and .5 - .7 cm. wide at widest part near middle, tapering to an oblique rounded point.

Weight: 60,000 per pound.

B. Seedling as it Appears Above Ground, About to shed Seed-Coat. Pinkish stem.

C. Seedlings with Cotyledons.

Stem pinkish color. Cotyledons green, linear 2 - 2.5 cm. long, tapering point. 5 to 7 in number, usually 6.

D. Seedling One Year Old, showing that it is well established at this age.

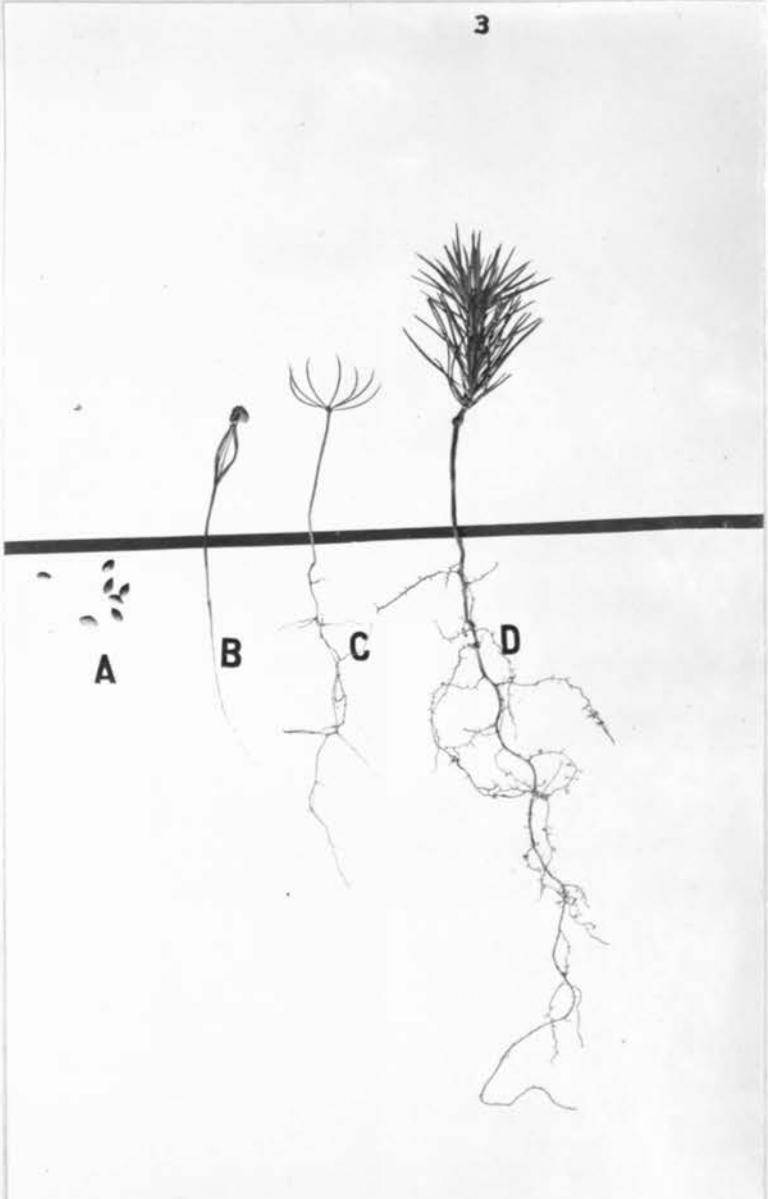

PLATE NO. XXVII.

PINUS SYLVESTUS

Scotch Pine.
(Size 5/8)

PLATE NO. XXVII.

PINUS SYLVESTUS Size 5/8

Scotch Pine.

A. Seed, Color: Dark greyish or brownish white. Wing greyish with darker parallel stripes.

Size: 4 mm. long, 3 mm. wide, rounded to triangular shaped. Wing 8-10 mm. long, 5-7 mm. wide at widest part near middle, gradually tapering to an almost acute apex.

Weight: 90,600 per pound.

B. Seedling as it appears Above Ground, about to shed Seed-Coat.

Hypocotyl green.

C. Seedling with Cotyledons.

Cotyledons 1.4 - 1.7 cm. long, linear with long tapering point. 4-7 in number.

D. Seedling One Year Old.

Well established.

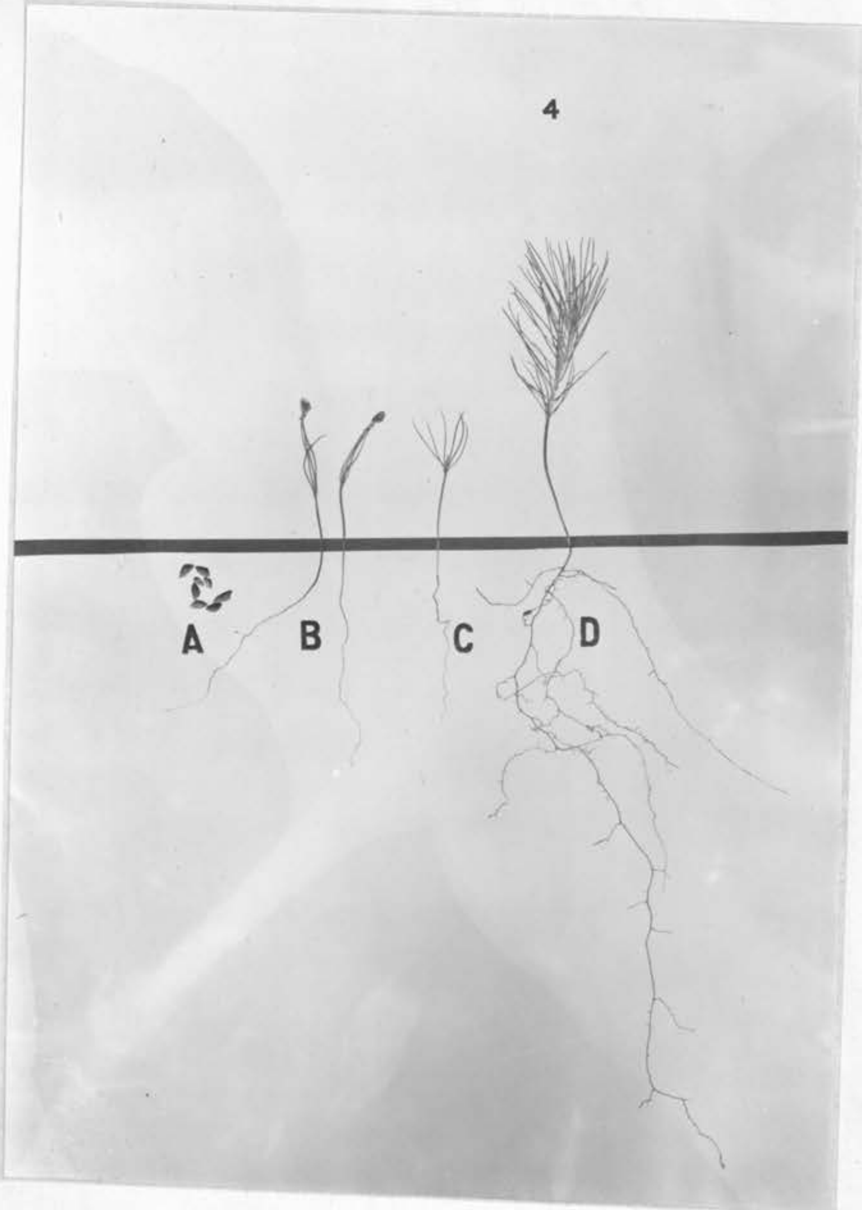

PLATE NO. XXVIII.

PINUS DIVARICOTA

Jack Pine.
(Size 5/8)

PLATE NO. XXVIII.

PINUS DIVARICOTA Size 5/8

Jack Pine.

A. Seed, Color: Almost black, dull brown spots. Wings very light brown with darker brown stripes and margin.

Size: 4 mm. long, 2 mm. wide at widest part, triangular in shape. Wings 8 mm. to 1 cm. long, 3-4 mm. wide at widest part near middle, broad rounded apex.

Weight: 120,000 per pound.

B. Seedlings as they appear above ground, about to shed seed-coat.

Hypocotyl pale pink.

C. Seedling with Cotyledons.

Cotyledons 1.2 - 1.8 cm. long, narrow long tapering point, green. 4-7 in number.

D. Seedling One Year Old.

Well established as shown by root system.

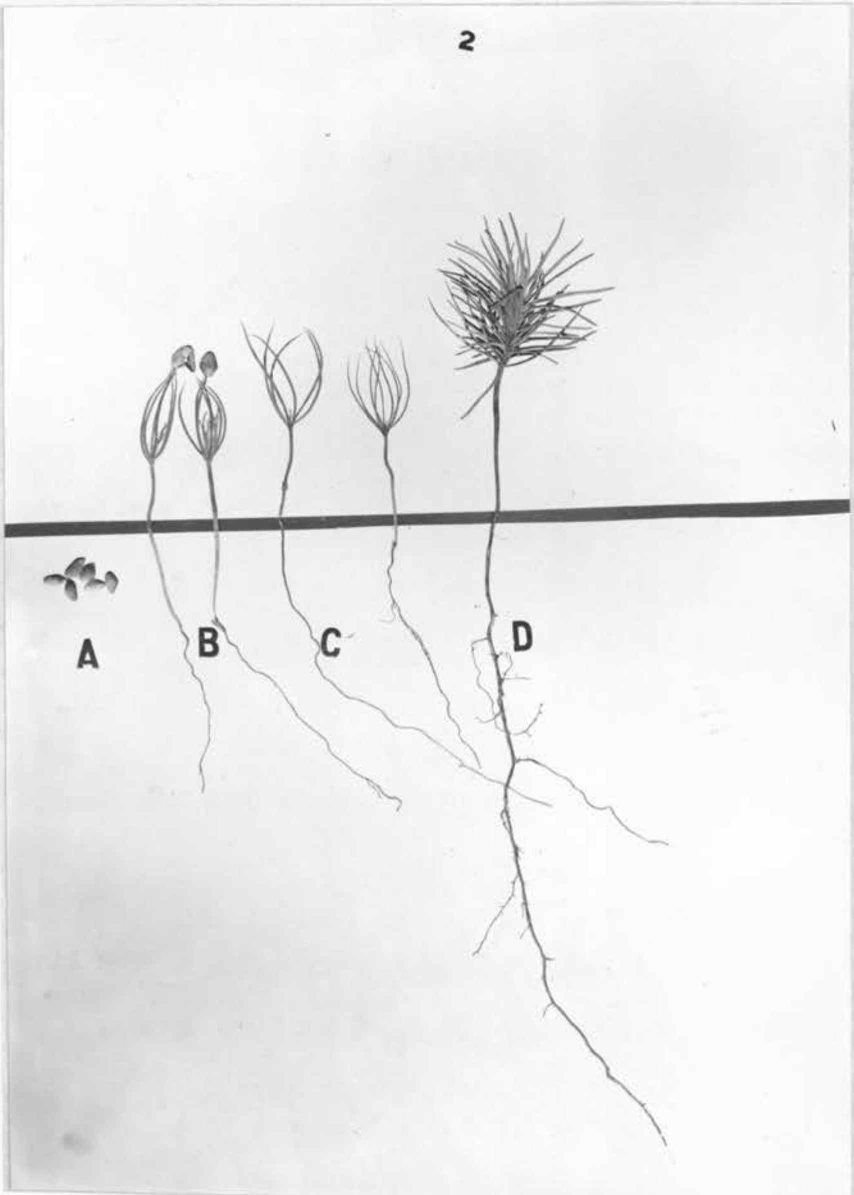

PLATE NO. XXIX.

PINUS CORCIANA

Corcican Pine.
(Size 5/8)

PLATE NO. XXIX.

PINUS CORCIANA Size 5/8

Corcican Pine.

A
Seed, Color: Light brown, motled with black to a dark brown. Wings brown.

Size: 5-7 mm. long, 3-4 mm. wide. Usually triangular shaped. Wings 1.5 - 2 cm. long, .7 - 1 cm. wide at widest part near middle taper to almost pointed apex.

Weight: 30,200 per pound.

B. Seedlings as they Appear Above Ground, About to shed Seed-Coats.

C. Seedlings with Cotyledons.

Stems and cotyledons green. Cotyledons linear 2-1/2 cm. long with tapering point. 6 to 7 in mumber.

D. Seedling One Year Old, showing tap root.

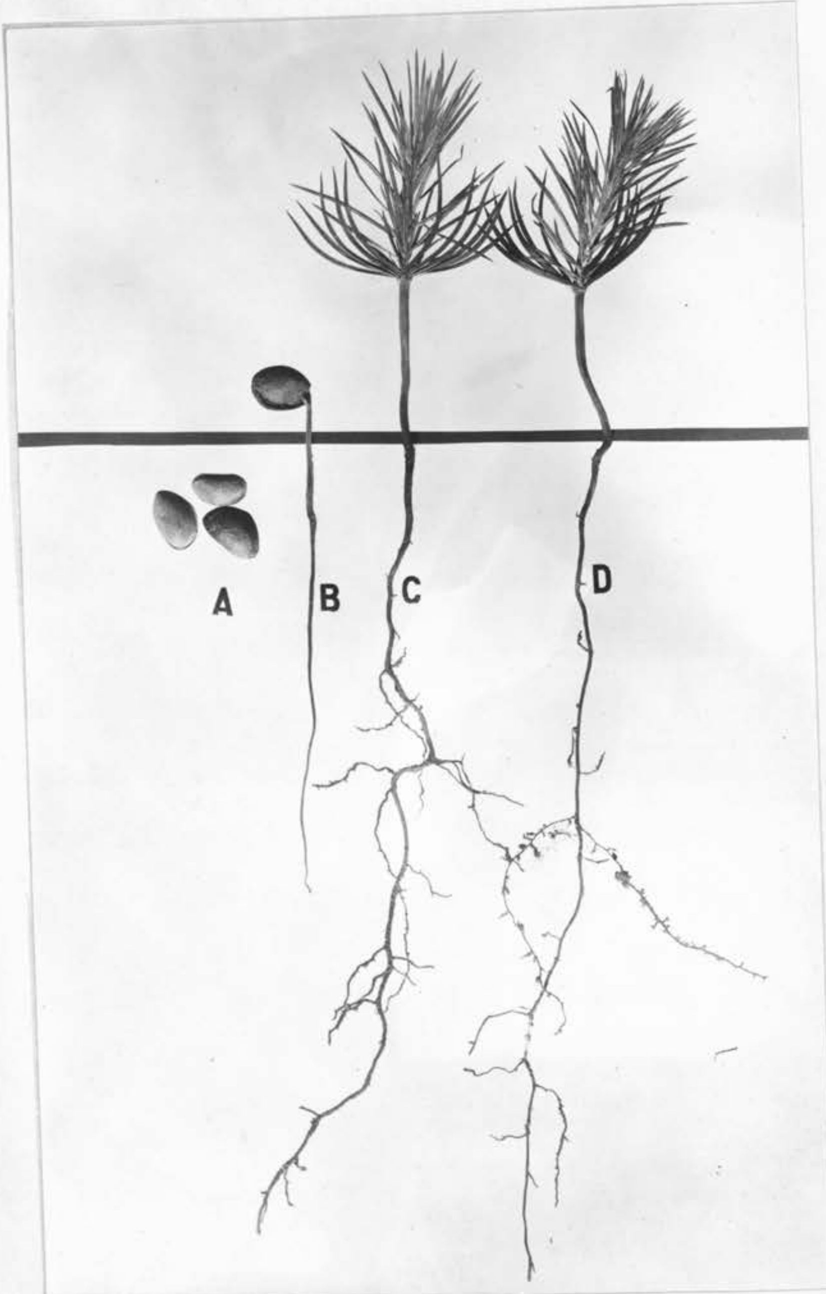

PLATE NO. XXX.

PINUS LAMBERTIANA

Sugar Pine.
(Size 4/5)

PLATE NO. XXX.

PINUS LAMBERTIANA Size 4/5

Sugar Pine.

A. Seed, Color: Dark brown, shiny on one side - side next to cone - and a greyish brown on other side. Wings dark brown.

Size: 1-1.5 cm. long, 1-1.2 cm. wide. Very thick, oblong to triangular shape. Wings 1.5 - 1.8 cm. long, 1.5 cm.wide. Widest at top with very slightly rounded top.

Weight: 2,370 per pound.

B. Germinated Seed just as Seed-Coat Pushes above Ground, Showing Deep Root Developed.

C & D Seedlings One Year Old. Well developed root systems. Cotyledons 3.5 - 4 cm. long. Green, 12 - 16 in number, tapering point. Stem reddish green.

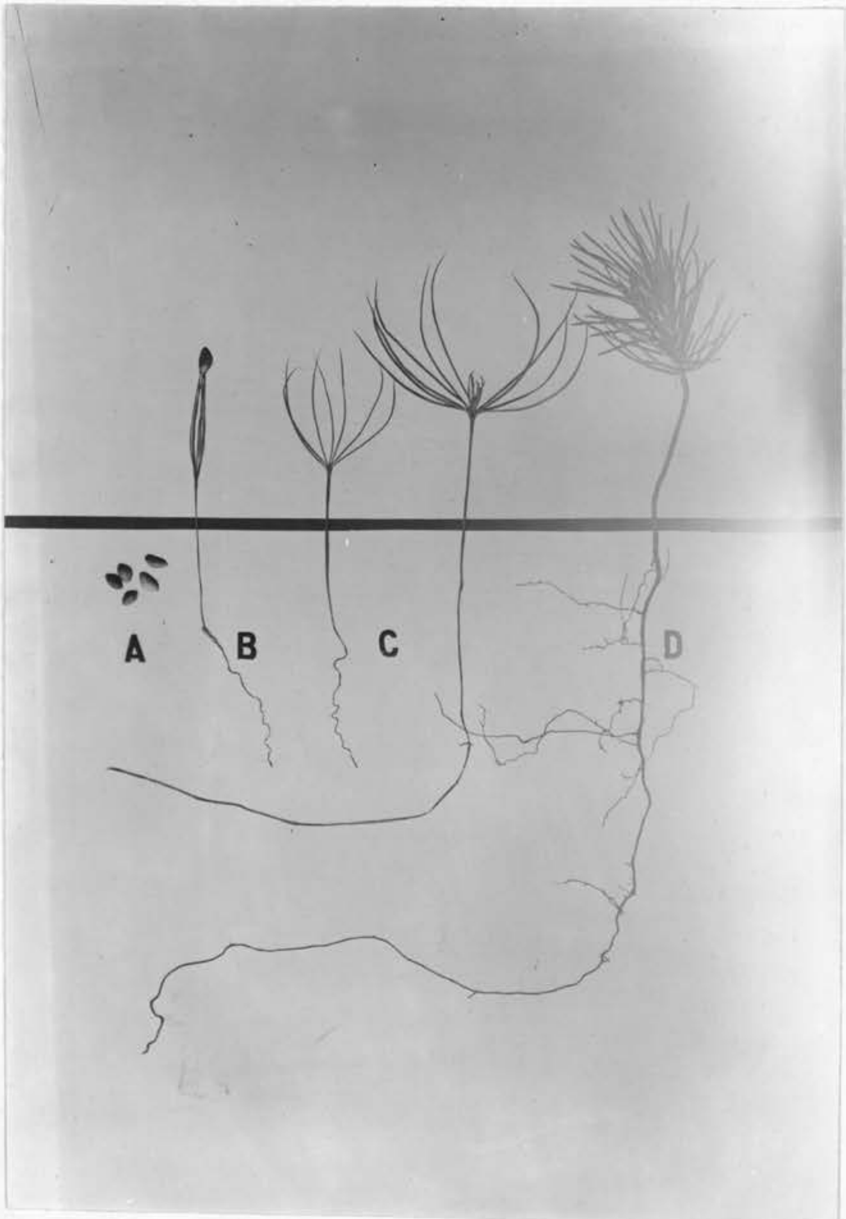

PLATE NO. XXXI.

PINUS AUSTRIACA

Austrian Pine.
(Size 1/2)

PLATE NO. XXXI.

PINUS AUSTRIACA Size 1/2

Austrian Pine.

A. Seed, Color: Greyish brown, often mottled with darker brown. Slightly shiny on one side. Wings light grey, darker near the seed, slightly, striped.

Size: 6-7 mm. long, 4 mm. wide, rounded to triangular. Wings 1.5 - 2 cm. long, .8 - 1 cm. wide at widest part near middle, abrupt taper to almost pointed apex.

Weight: 26,000 per pound.

B. Seedling as it Appears Above Ground, about to shed Seed-Coat.

Hypocotyl pale pink.

C. Seedlings with Cotyledons.

Cotyledons linear 2.5 - 3 cm. long, green. 6 and 7 in number.

D. Seedling One Year Old, Showing long tap root formed.

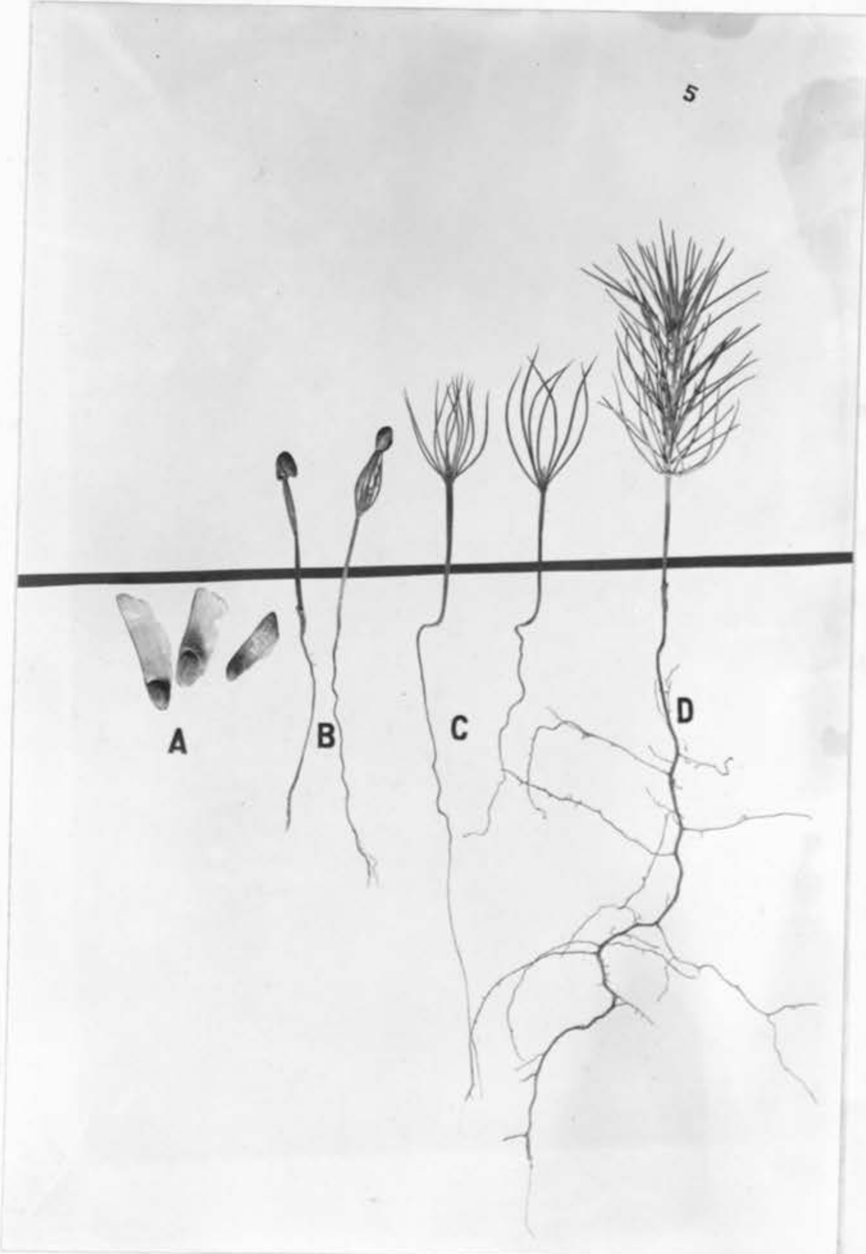

PLATE NO. XXXII.

PINUS PONDEROSA

Yellow Pine.
(Size 1/2)

PLATE NO. XXXII.

PINUS PONDEROSA Size 1/2

Yellow Pine.

A. Seed, dry, Color: Light brown to almost black, usually pale brown, mottled with black.

Size: 5-9 mm. long, 4-6 mm. wide, compressed at apex, well rounded below. Wings light to dark brown, 2-1/2 - 3-1/2 cm. long and 1-1/2 - 2-1/2 cm. wide at middle, gradually tapering to oblique apex.

Weight: Average 12,000 seeds per pound.

B. Seedling as it Appears Above Ground.

Hypocotyl and cotyledons green.

C. Seedlings with Cotyledons.

Green, Cotyledons 3-4 cm. long, linear, tapering point, 5-9 in number.

D. Seedling One Year Old, Showing deep root system developed, suited for dry situations.

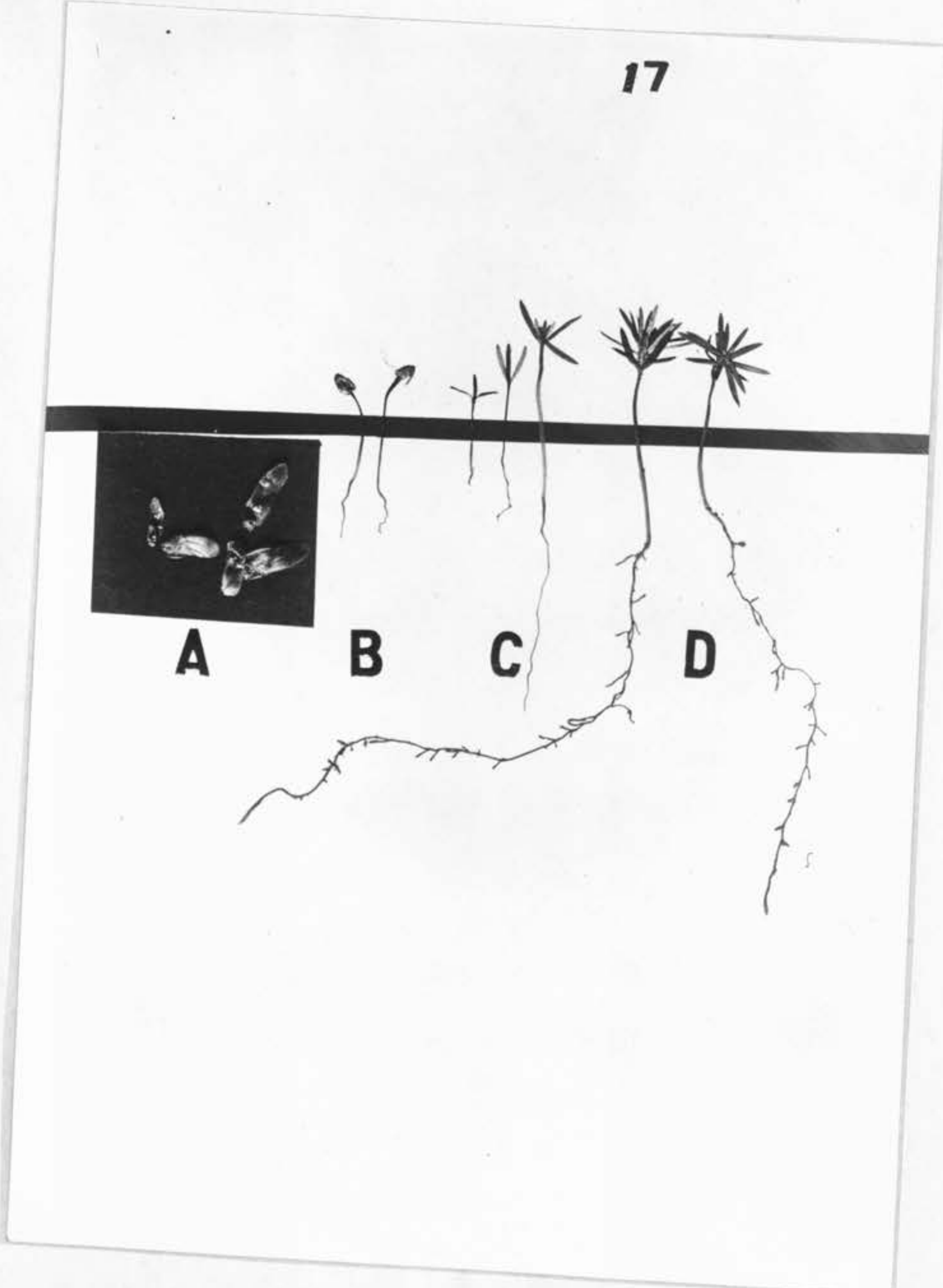

PLATE NO. XXXIII.

TSUGA HETEROPHYLLA

Western Hamlock.
(Size 1-1/2)

PLATE NO. XXXIII.

TSUGA HETEROPHYLLA Size 1-1/2

Western Hemlock.

A. Seed, Color: Light plain brown, with wings of a very light brown tinge, almost gauzy in texture.

Size: 1 mm. wide, 2 mm. long. Wings .5 to 1 cm. long, 4 mm. wide. Wing attached more than half way around seed and as broad at base as at middle with rounded apex.

Weight: 275,000 per pound.

B. Seedling as it Appears Above Ground, about to shed Seed-Coat.

Hypocotyl brownish green.

C. Seedlings with Cotyledons.

Hypocotyl brownish green. Cotyledons 5-6 mm. long with tapering point. Pale green with dark green mid rib. Number 3-5, usually 3.

D. Seedlings One Year Old.

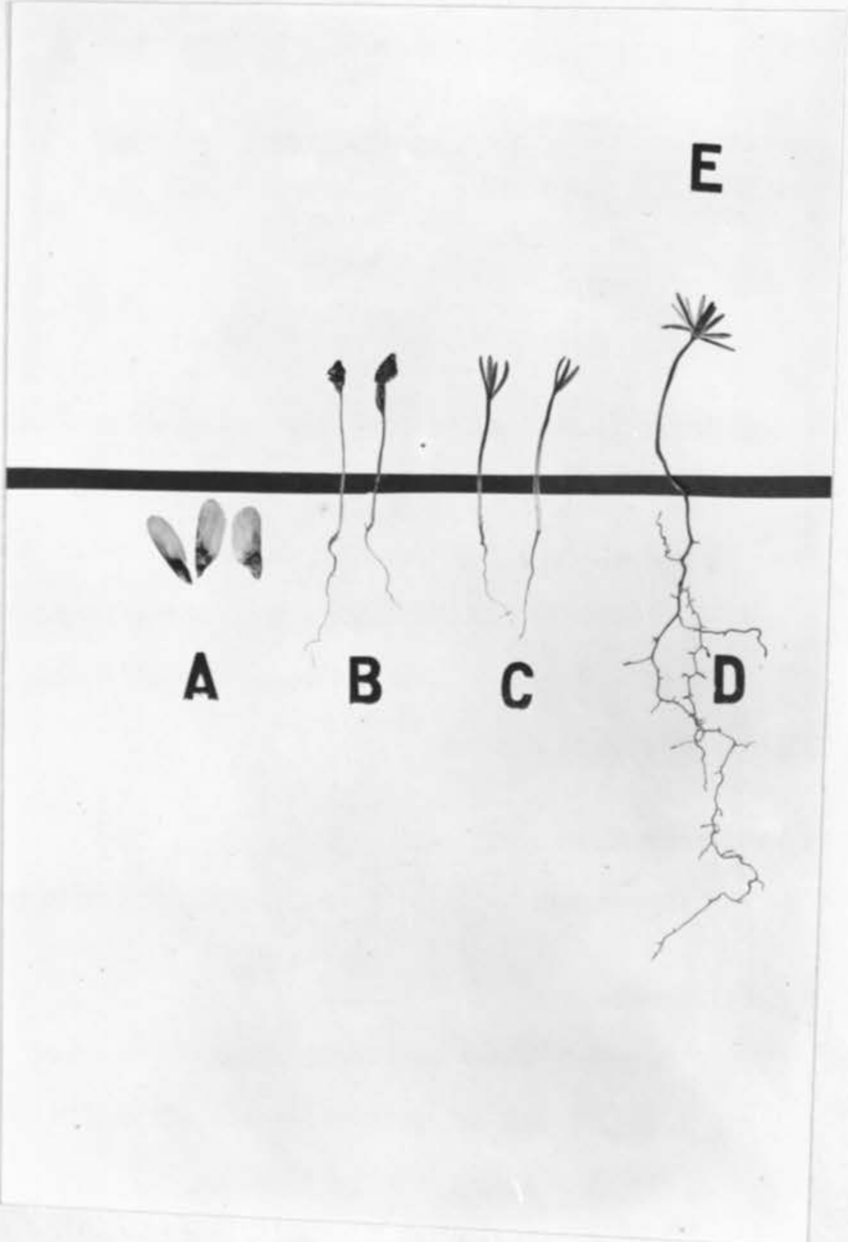

PLATE NO. XXXIV.

TSUGA MERTENSIANA

Mountain Hemlock.
(Size 7/9)

PLATE NO. XXXIV.

TSUGA MERTENSIANA Size 7/9

Mountain Hemlock.

A. Seed. Color: Brown to deep reddish brown. Wings pale brown merging to a reddish brown where wing is attached to seed.

Size: 2 mm. wide, 5 mm. long, triangular shaped. Wing 5-6 mm. wide at widest part near top. 1 cm. long. About equal width throughout with broad rounded apex.

Weight: 260,000 per pound.

B. Seedlings as they Appear Above Ground.

Hypocotyl reddish tinge. Cotyledons pale green.

C. Seedlings with Cotyledons.

Cotyledons 4-5 mm. long, linear with short tapering points. Mid rib not as distinctive as in Tsuga heterophylla. 3-5 in number, usually 3 or 4.

D. Seedling One Year Old.

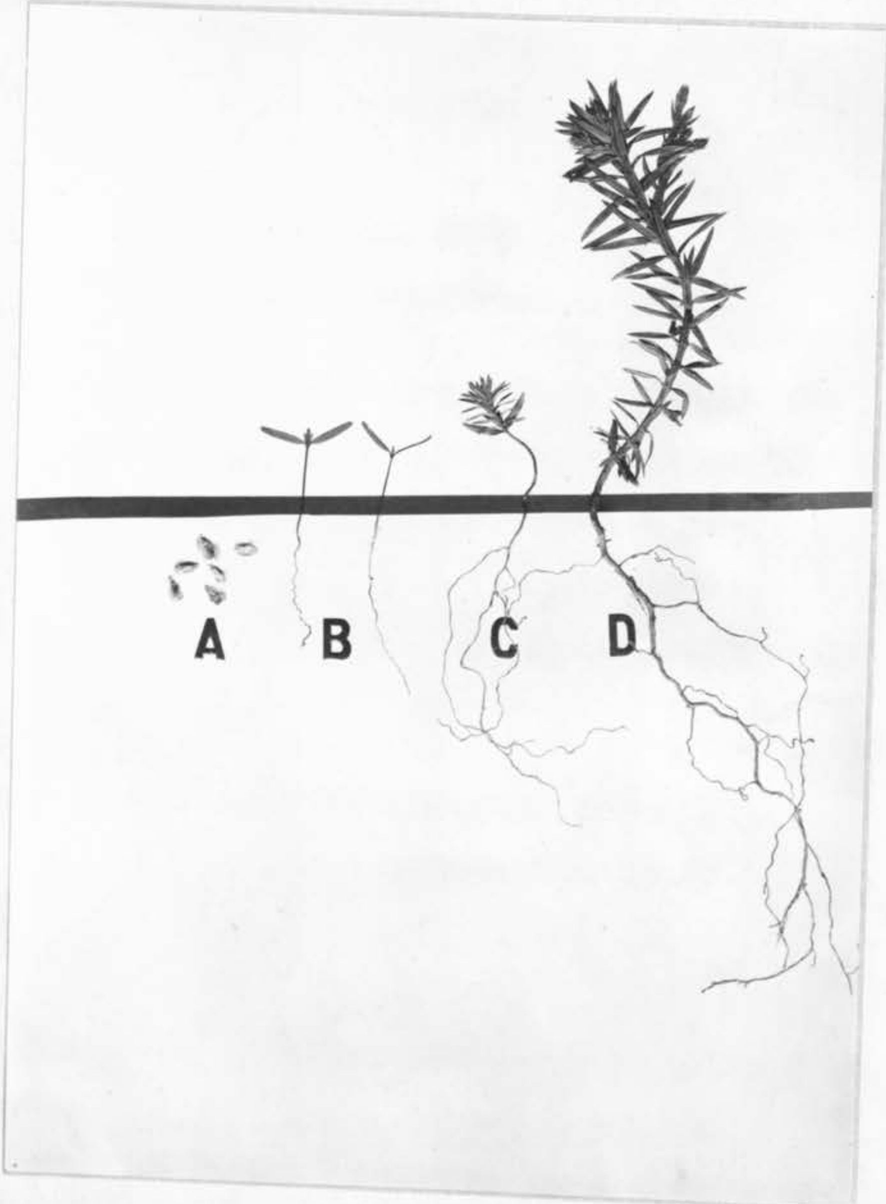

PLATE NO. XXXV.

THUYA PLICATA

Western Red Cedar.
(Size 5/6)

PLATE NO. XXXV.

THUYA PLICATA Size 5/6

Western Red Cedar.

A. Seed, dry. Color: Brown with lighter brown wings.

Size: 3 mm. long, narrow; wings 4 mm. long and 3 mm. wide including wings. Wings usually unequal, forming obcordate apex with seed.

Weight: 220,000 per pound.

B. Seedling with Cotyledons.

Hypocotyl pale pink color; cotyledons linear 6 mm. long, green, two in number.

C. Seedling One Year Old.

D. Seedling Three Years Old. First true leaves forming. This shows that it takes the seedling a long time to establish itself and must have favorable conditions for more than one season.

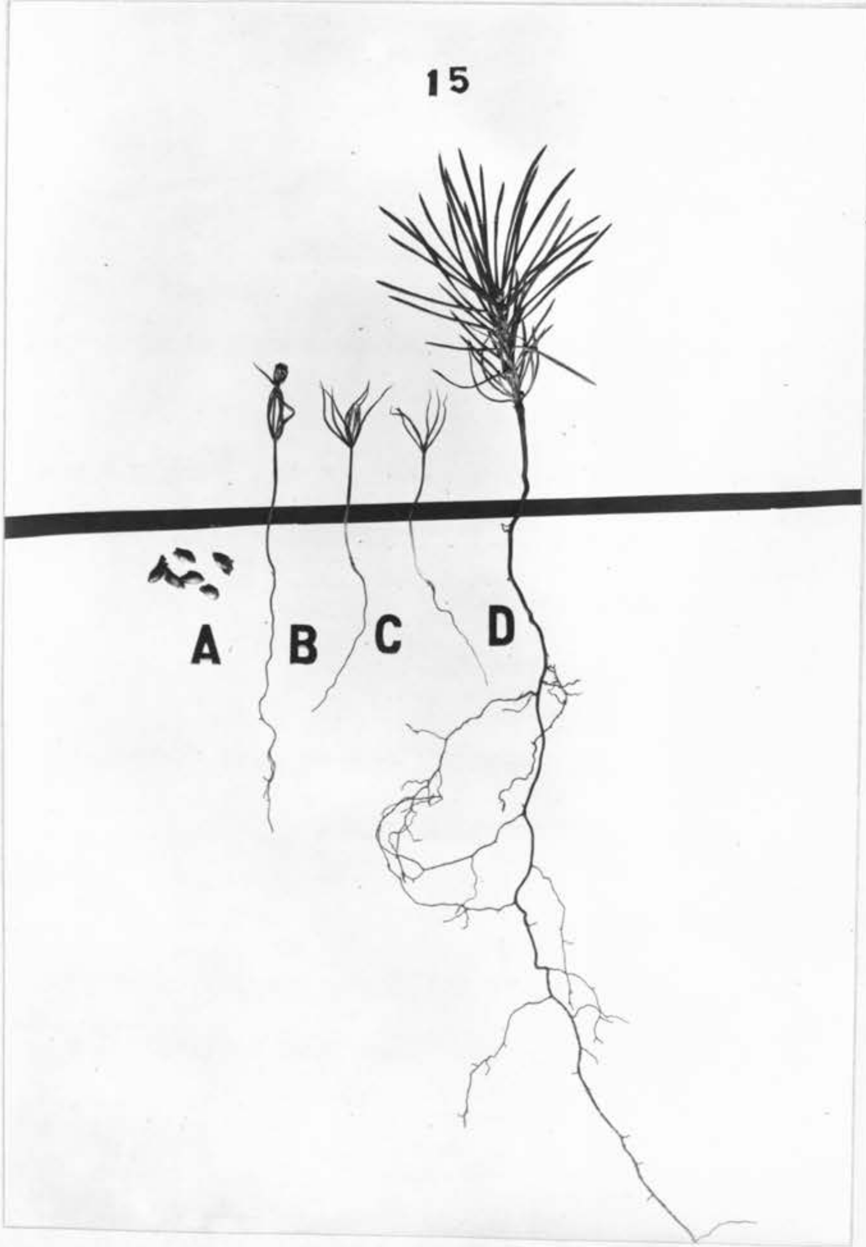

PLATE NO. XXXVI.

LARIX OCCIDENTALIS

Western Larch.
(Size 3/4)

PLATE NO. XXXVI.

LARIX OCCIDENTALIS Size 3/4

Western Larch.

A. Seed, Color: Greyish, mottled with brown to a shiny brown. Wings pale brownish.

Size: 4-5 mm. long, 2.5 - 3 mm. wide. Wings, 8 mm. to 1 cm. long and 4 - 6 mm. wide at widest part near middle, taperingto rounded apex.

Weight: 113,200 per pound.

B. Seedling as it Appears Above Ground, about to shed Seed-Coat.

Hypocotyl, reddish pink.

C. Seedlings with Cotyledons.

Cotyledons 1- 1-1/2 cm. long, very narrow, linear with tapering point. Stem pink reddish color. Cotyledons green, 5 - 7 in number.

D. Seedling One Year Old, Showing it well established.

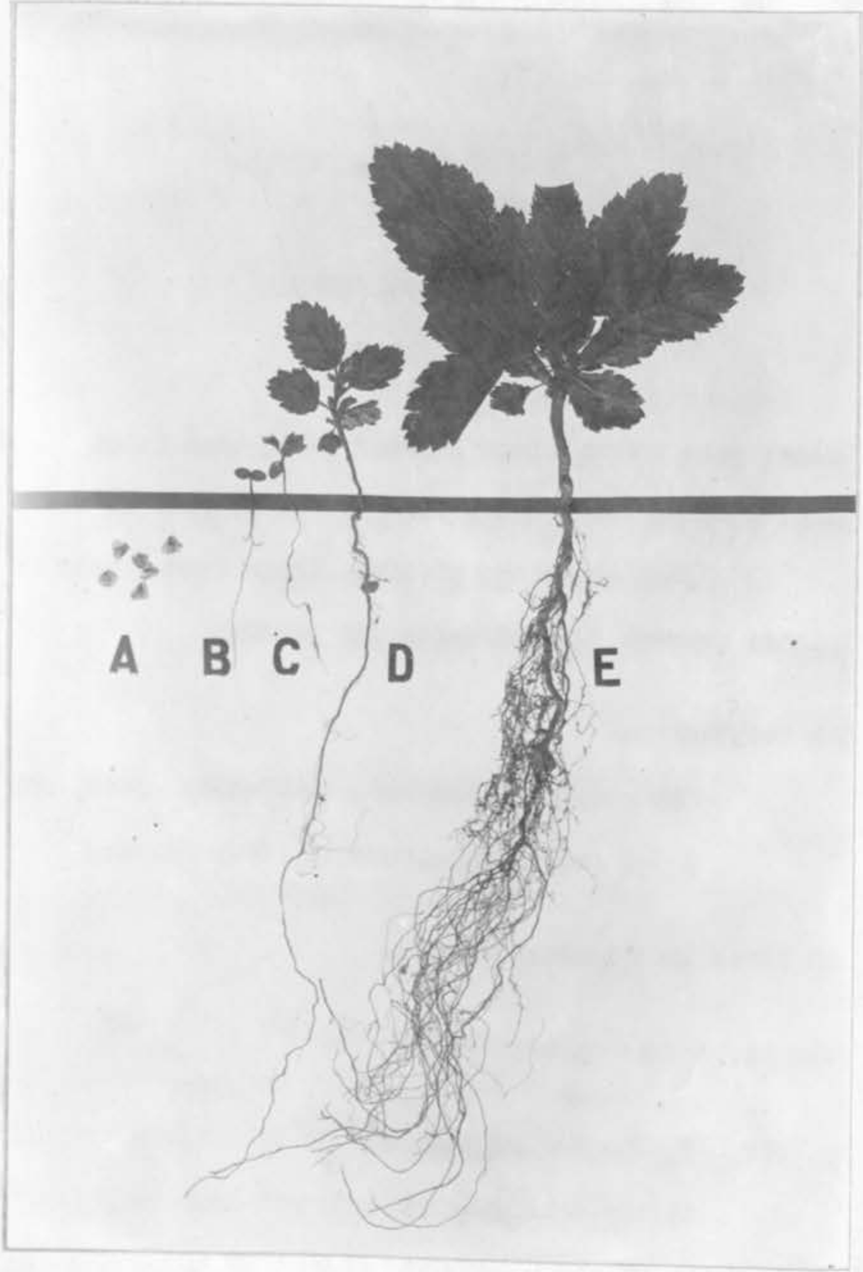

PLATE NO. XXXVII.

ALNUS RHOMBIFOLIA

Alder.
(Size 6/7)

PLATE NO. XXXVII.

ALNUS RHOMBIFOLIA Size 6/7

Alder.

A. Seed, Color: pale brown, wings lighter color than seed.

Size: 2-3 mm. long, 3 mm. wide at widest part of wings and seed, just above the middle. Wings form retuse apex with seed.

Weight: Average 645,000 seeds per pound.

B. Seedling with Cotyledons,

Hypocotyl pinkish red, cotyledons green, ovate, 2 mm. long, 1-1/2 mm. wide, glabrous; 2 in number.

C. Seedling with first true leaves forming.

D. Seedling after it becomes established.

E. Seedling One Year Old, Showing how thoroughly it becomes established even though it has a slow start and must have very favorable conditions.

A study of the foregoing plates shows the different development of the various species and the noticeable thing is that the species which require the most moisture are the ones in which the seedlings are the slowest in establishing themselves. The natural result of this is that these species are always found near the streams and on moist slopes. The Cedar takes about three years to establish its seedling while the Yellow Pine or Douglas Fir seedling is well established at the end of the first season. The Alder is included in these plates because it is one of the species which invariably is found along the streams and in all wet places and as mentioned before it is one of those trees which requires more than one season to establish its seedling or at least a very favorable season for the entire summer. Hemlock is another example of a species with a small seedling the first year, although it will produce a greater height growth than its associates after the seedling is established, that is the third or fourth year. It is clearly seen also that the species which have the larger seeds establish their seedlings earliest and in the more unfavorable places.

VIABILITY OF SEED.

The viability of the seed is the chief factor that determines the species and amount of reproduction following the burns and clear cuttings because the seed must not only be there but it must also be germinable seed. The foregoing work shows that all of the species present before the fire are represented in the reproduction following the fire. The question now remains: How long has this seed been there? It will be several years before this is finally settled but it is not going beyond our present knowledge to assume that it might be covered in the forest floor for a number of years and wait for the favorable germination conditions which always follow the removal of the forest, either by fire or cutting. We know that the seeds of other plants are viable for long periods and in my own experience I have known

Wild Oat seed (avena fatua) to remain in the soil for seven years anf then produce a heavy stand the year it was plowed up. The field had grown to wild oats so it was sown with grass and pastured for seven years with no production of seed but at the end of seven years the seed turned under by the plow when it was seeded to grass was again brought to the surface and germinated. This was in southern Minnesota where it was exposed to severe winters and varying conditions during the summer.

Becker[1] draws the conslusion that oxygen acts as a stimulant in seed germination and many of the conditions under which the seed germinates or does not germinate seems to bear this out.

Hatfield's[2] work on the Vitality of Seed showed that the Hibiscus militaris germinated after 10 years, Rocky Mountain Columbine after 6 years, Tobacco, Verbenas, Ageratum after several years storage.

Duval[3] found the following seeds germinated after being buried in layers of clay, not below the frost line, for three and a half years: Trifolium pratense, Trifolium repens, Polygomum avariculare, Bursa pastoris, Anthemis cotula. The soil was taken into the green-house and the seed germinated.

Beal[4] secured some germination from the following seeds after they had been stored in soil for 20 years: Amaranthus retroflexus, Brassica nigra, Capsella, Bursa pastoris, Lepidium virginicum, Anthemus cotula, Malva rotundafolia, Rumex crispus, Verbascum thapsus, Stellaria media, Polygomum hydropiper.

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(1) Becker, H. "Uber die Keimung verschiedenartiger Fruchte und Samen bei derselben Species. Beih. Bot. Centralbl. 29:21-143, 1912.

(2) Hatfield, T.D. Vitality of Seed, Gardan and Forest p 297, 1897.

(3) Duval, Bot. Gaz. 37-146, 1904.

(4) Beal. Vitality of Seeds, Bot. Gaz. 37-222, 1904.

All of these experiments show the viability of the seed of many of the common and well known seeds all having seeds with very thin seed coats and easily soaked with water then it is easily possible that the seed of the conifers with its resinous seed-coat would retain its vitality for a long time. The characteristics of some of the coniferous seeds are well known, such as the Western White Pine, Douglas Fir, Eastern White Pine, and Junipers. These seeds will often not germinate for two or three years even with the best of conditions in the nursery so they surely will remain as long and longer when on the forest floor under favorable germinating conditions, but at the same time under good storage conditions.

The investigations discussed here show that the Western White Pine (Pinus monticola) seed remained in the soil for 6 years; Douglas Fir (Pseudotsuga taxifolia) for 6 years; Noble Fir (Abies nobolis) for three years; Amabalis Fir (Abies amabalis) for five years; Western Hemlock (Tsuga heterophylla) for six years; Yew (Taxus brevifolia) for eight years; Western Red Cedar (Thuya plicata) for two years.

Conzet[1] showed that the seed of the Norway Pine (Pinus Resinosa) remained in the forest floor for three years and then produced a good germination.

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(1) Conzet, G. Master's thesis, University Minnesota, 1913.

SUMMARY AND CONCLUSIONS.

All forest trees and stands of forests produce sufficient seed to re-establish the type under favorable conditions, and the change of type or removal of a forest from any area once covered with forest, is due to other factors than production of seed.

Seed distribution is one of the most important factors controlling the establishment of a type.

Species producing larger seed, produce less seed.

Leaving seed plots has not proven successful because the seed was not distributed far enough from the seed-trees to re-seed the area. Leaving sufficient seed-trees to insure re-seeding, would take enough timber to make it prohibitive.

Single seed trees have not succeeded in the White Pine region of Idaho, because they are not wind firm, and two years after cutting most of them were blown down.

In the White Pine region of Idaho, reproduction cannot be depended upon more than about two chains from the seed trees.

In the Douglas Fir region of the Cascades along the Columbia River, reproduction of the Douglas Fir and its associates cannot be depended upon for more than four or five chains, and often less.

Seed is always present in a forest floor, sometimes covered with layers of litter and duff.

That the seed present at the time a forest is removed by fire or logging, is the source of the reproduction following, is shown by the preseding work.

Germination conditions are unfavorable in the shaded cool forest floor, hence seed is often left dormant for long periods.

By the removal of the forest, germinating conditions are always better and the seed left dormant germinates.

The size of the seedling is directly proportional to the size of the seed.

Seeds when dormant will withstand severe conditions as shown by chemical tests.

The seedling grown from a large seed becomes established much sooner and more permanently than the seedling grown from a small seed hence the former is able to obtain and hold possession of the more unfavorable sites.

Moisture is the chief factor in the establishment of the seedling while temperature is often a more important factor in germination.

The moisture loving species invariably produce small seeds and require one or more favorable seasons to establish their seedlings.

Common weed seeds having thin seed coats which are easily water soaked are known to be viable for twenty years and coniferous seeds are known to be viable for as long as six years. It is very reasonable to assume that the coniferous seeds are viable much longer. This will not be definitely known for some years.