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RESPONDING AND NON-RESPONDING INSTALLATIONS AS AFFECTED BY DIFFERENCES IN PLOT STAND STRUCTURES

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This report is a publication of the Regional Forest Nutrition Research Project, a cooperative program initiated in 1969 to provide forest managers with accurate growth data for managed stands of Douglas-fir and western hemlock in western Oregon and western Washington. Over 30 Pacific Northwest forest industry companies, state and federal agencies, and fertilizer manufacturers provide support and direction for the Project. The RFNRP Report Series is intended to enhance communication of forest fertilization research results within the RFNRP community. Prepared to meet internal RFNRP needs, reports in the series may be descriptions of work in progress as well as final statements of research results.

SUMMARY

The relationship between installation (site-specific) volume growth response to nitrogen (N) fertilizer and the initial diameter distributions of control plots and fertilized plots was explored for unthinned and thinned Douglas-fir installations. Some of the more important results were:

1. Of the 91 installations analyzed in this study, 42 were found to have heterogeneous initial diameter distributions between control plots and fertilized plots.

2. Thinning did not bring about parity in initial diameter distributions in many installations. Sixteen of 31 thinned were found to have heterogeneous diameter distributions between control plots and fertilized plots.

3. Ten installations had negative volume growth responses. In general, the control plots contained several more large trees than the fertilized plots in these installations. Five of these ten installations were found to have statistically different ($p < .05$) diameter distributions between treatments.

4. Of the ten installations with the largest volume growth responses, six were found to have statistically different ($p < .05$) diameter distributions between treatments. In general, the fertilized plots of these six installations contained more trees in the larger diameter classes than the control plots and the control plots had a greater density (stems per acre) than the fertilized plots.

These results indicate that installation volume growth response estimates based on treatment comparisons are suspect for those installations that had heterogeneous initial diameter distributions between treatments.

A review of the literature revealed two methods that may be used to compute volume growth response estimates when diameter distribution differences exist between treatments: "stand structure analysis" and a method that uses pretreatment increment data. Additional research is required before either of these methods can be successfully applied to RFNRP data.

RESPONDING AND NONRESPONDING INSTALLATIONS AS AFFECTED BY DIFFERENCES IN INITIAL PLOT DIAMETER DISTRIBUTIONS

D. Opalach and C. E. Peterson

INTRODUCTION

It is well known that stand growth is related to stand structure. Likewise, growth response to fertilizer depends on stand structure (Barclay and others 1982; Ballard 1984). These observations have important implications when attempting to determine site-specific responses to fertilizer for Regional Forest Nutrition Research Project (RFNRP) installations. To illustrate the potential problems which may arise when computing a site-specific response, consider the following scenario. Suppose two plots in a young second-growth Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) RFNRP installation contain several more large trees than the remaining four plots at the time of installation establishment. If none of these six plots were treated, then the two plots with the several more large trees would have greater volume periodic annual increments (PAIs) than the remaining four plots. This is true because tree volume growth is positively correlated with tree diameter in untreated plots such as these (e.g., see RFNRP 1974 or Barclay and others 1982). Thus, it could be said that these two plots with the several more large trees have a superior structure relative to the remaining four plots. Now suppose these two plots with the several more large trees are control plots and the other four plots are treated with nitrogen (N) fertilizer (two plots are treated with 200 lbs N/A and the other two are treated with 400 lbs N/A). Since growth response is defined as the difference between the growth rates of fertilized and unfertilized stands, response estimates for this installation may be artificially small due to the superior structure of the control plots.

The effects of diameter distribution differences between treatments on response to fertilizer were addressed in a RFNRP Biennial Report (RFNRP 1974). Nonhomogeneous diameter distributions between treatments within an installation were thought to be the reason for nonresponse in one installation and an anomalous high response in another. Also, it was demonstrated that site-specific or installation response estimates could be improved by using diameter distribution information.

In order to further explore the effects of initial diameter distribution differences between treatments on volume growth response to fertilizer, this study was undertaken. The primary objectives of the analysis were to answer the following sets of questions:

1. How should the similarity or dissimilarity of stand structures be evaluated? Can this evaluation be done subjectively? What statistical techniques are available to quantitatively perform this evaluation?

2. How many installations have initial diameter distributions that differ between treatments? What is the nature of these differences?

3. What can be said about the relationship between response estimates and plot diameter distributions? What methods can be used to obtain valid response estimates when diameter distribution differences exist between treatments?

Results from this study will provide a base for future studies on stand structure. One such study involves an investigation of the effects of fertilization on diameter distribution changes over time. Another study is an analysis of the size distribution of mortality due to fertilization.

METHODS

Data Collection

The data used in this study come from RFNRP installations established during 1969-1972 in western Oregon and Washington. Installations selected for inclusion in this study were located in natural second-growth Douglas-fir stands where 80 percent or more of the standing basal area was in Douglas-fir.

Each installation contained six plots: two control plots, two plots fertilized with 200 lbs N/A, and two plots fertilized with 400 lbs N/A. Nitrogen was applied in the form of urea. For this study, only data from control (0N) plots and plots fertilized with 200 lbs N/A (2N) were used.[1] If a 0N plot or a 2N plot had been dropped from an installation for any reason, then that installation was not included. Plots in each installation were one-tenth acre or greater in size.

A total of 91 installations were used in this study (Table 1), 31 of which were thinned to 60 percent of their initial basal area at the time of installation establishment. For additional details concerning the RFNRP experimental design and stand selection criteria, see Hazard and Peterson (1984).

Analytical Methods

Stand and stock tables were constructed for each installation by combining data from plots with the same treatment. Each table included:

[1] In this report, 0N and 2N are treatment codes that refer to the absence or presence of fertilizer treatment for both unthinned and thinned plots. The usual RFNRP convention of designating thinned plots as either 0T plots or 2T plots is not used here as a matter of convenience.

stems per acre (SPA), basal area per acre, and cubic foot volume including top and stump per acre (CVTS) by diameter class at the time of installation establishment and eight growing seasons after treatment. Volume was computed using the tarif system (Turnbull and others 1972).

Histograms of initial SPA by diameter class (diameter distributions) and histograms of initial CVTS by diameter class were constructed for each installation. Relative cumulative proportion (RCP) graphs of initial SPA and initial CVTS were also constructed. These graphs show the percentage of SPA (or CVTS) contained in all diameter classes above a given diameter class relative to the treatment that has the greatest total SPA (or CVTS). The main advantage of a RCP graph over the standard cumulative proportion graph is that the treatment with the greatest stocking in all diameter classes above a given diameter class can be readily identified.

Volume difference (VDIFF) and average 8-year gross volume growth response (RESPONSE) were computed for each installation. VDIFF and RESPONSE were defined as:

VDIFF	=	average volume of 2N plots at the time of installation establishment	minus	average volume of ON plots at the time of installation establishment
RESPONSE	=	average gross volume PAI computed from 8-year growth on 2N plots	minus	average gross volume PAI computed from 8-year growth on ON plots

In order to quantitatively evaluate the similarity between the initial diameter distributions of the ON plots and the 2N plots for a given installation, diameter data for plots with similar treatments were combined. That is, the diameter data for both ON plots were pooled to form a combined ON plot and the diameter data for both 2N plots were pooled to form a combined 2N plot. These combined data were then subjected to two different statistical tests: a two-sample Kolmogorov-Smirnov (K-S) test (Hollander and Wolfe 1973) and a two-sample chi-square test (Hogg and Tanis 1977). These tests were selected because of their widespread use in disciplines other than forestry. Since neither of these tests is often used in forestry research, it was not clear which test would give better results. The hypotheses for each of the tests are:

HO: The diameter distribution of the combined ON plots is identical to the diameter distribution of the combined 2N plots at the time of fertilizer application

HA: The diameter distribution of the combined ON plots is different from the diameter distribution of the combined 2N plots at the time of fertilizer application

where HO is the null hypothesis and HA is the alternative hypothesis. Both tests are designed to detect all departures from the null hypothesis. The two-sample K-S test has recently been used by Green and others (1985) to test for equality between two diameter distributions. No similar reference was found for the two-sample chi-square test. Both tests were conducted at the .05 level of significance.

In order to perform the two-sample chi-square test for an installation, the diameter distribution of the combined ON plots and the diameter distribution of the combined 2N plots were divided into 12 classes of equal width. Twelve diameter classes were chosen after considerable investigation.[2] The width of each class was determined by finding the trees with the largest and smallest diameters in either set of

[2] It was not clear what the optimum number of classes was to use for this purpose. Ford (1975) primarily used 12 classes when he constructed histograms of plant size, but he did not construct histograms for the purpose of performing statistical tests.

combined plots. These two values were then subtracted and divided by 12 to obtain the width of each class. If a class was found not to contain any trees from both the ON plots and 2N plots, then the class was eliminated from the calculation of the chi-square statistic and the degrees of freedom were adjusted accordingly.

RESULTS AND DISCUSSION

Tables and Graphs

Although the complete set of stand and stock tables, histograms, and RCP graphs for each installation could not be reproduced in this report, the table and graphs for installation 21 are offered as examples. Data contained in a stand and stock table (Table 2) are displayed as histograms and RCP graphs (Figures 1 through 4).

Subjective evaluation of stand structure similarity of combined ON plots and combined 2N plots proved to be difficult using these graphs for several reasons. First, the authors were not able to agree on the similarity or dissimilarity of stand structures for many installations. Second, the authors found that their determination of stand structure similarity depended on the measure of stand structure being analyzed. That is, it was found that an evaluation based on reviewing diameter distributions often differed from an evaluation based on reviewing CVTS by diameter class distributions. For these reasons, it was concluded that the similarity of two stand structures could not be assessed subjectively.

Response and Initial Volume Differences

On average, thinned installations responded more to fertilizer than unthinned installations (Table 3). Only ten installations had negative volume growth response estimates. A negative volume growth response does not necessarily indicate that N fertilizer caused a reduction of growth on 2N plots; it merely indicates that the 8-year growth of ON plots exceeded the 8-year growth of 2N plots. For a detailed discussion of regional 8-year volume growth response in both unthinned and thinned Douglas-fir, see RFNRP (1982).

Initial volume differences varied over a much wider range for unthinned installations than for thinned installations (Table 3). Clearly, thinning increased the similarity of plots within an installation with respect to initial volume. It should be noted that each of the installations that had a negative volume growth response also had a negative initial volume difference.

There was a significant positive correlation ($p < .01$) between volume growth response and initial volume difference for the unthinned installations (Figure 5). In general, negative or small positive volume growth responses were associated with negative initial volume differences, and positive volume growth responses were associated with very large positive initial volume differences. For thinned installations, the correlation between these two variables was not significant ($p > .05$; Figure 6).

Distribution Tests

The results from the two-sample K-S test and the two-sample chi-square test were different for several installations (Table 1). Overall, the K-S test rejected the null hypothesis more often than chi-square test (Table 4) indicating that the chi-square test may be more conservative than the K-S test.

During the analysis it was discovered that chi-square test results were extremely sensitive to the number of classes used to perform the test. Also, it is known that the power of the one-sample K-S test is greater than the power of the one-sample chi-square test (Ostle 1963). Hence, it may be that the power of the two-sample K-S test is greater than the power of the two-sample chi-square test. For these reasons, the two-sample K-S test results were thought to be better than the two-sample chi-square test results.

An attempt was made by the RFNRP to establish research installations in uniform well-stocked stands (Hazard and Peterson 1984). However, if diameter distribution is considered a criterion of uniformity, then the K-S test results show that this objective was not met for 26 of the 60 unthinned installations analyzed in this study (Table 4). Although one might assume that thinned installations would exhibit a greater degree of diameter distribution homogeneity across plots, the K-S test results show that this is not the case. The null hypothesis of no difference in initial diameter distribution between 0N plots and 2N plots was rejected for 16 of the 31 thinned installations (Table 4).

Overall, 42 of the 91 installations were identified by the two-sample K-S test as having significantly different diameter distributions between treatments (Table 4). There was no clear relationship between volume growth response and test rejection (Table 1). That is, if the installations were ranked in a list by volume growth response, then installations for which the null hypothesis was rejected would be uniformly distributed throughout the list.

Nonresponding Installations

Of the ten installations with negative volume growth responses, five were found to have significantly different ($p < .05$) diameter distributions between 0N plots and 2N plots (installations 10, 37, 74, 115, and 120). The nature of the differences between treatments varies slightly from installation to installation (Figures 7 through 11). Four of the installations (10, 37, 115, and 120) had 0N plots that had more trees in the larger diameter classes than the 2N plots. In addition to having different diameter distributions, these installations had markedly different initial densities between treatments (Table 5).

The other five installations that had negative volume responses, but not found to have significantly different diameter distributions between treatments, had small differences in density (Table 5). Inspection of the diameter distributions for these installations revealed that the 0N plots, in general, had a few more trees in the larger diameter classes than the 2N plots (Figures 12 through 16). It may be that these few trees represent enough of a difference between plots so that volume growth response estimates are biased.

There is reason to believe that the .05 level of significance was not an appropriate level to use in this application of the two-sample K-S test. It may be that two stands with diameter distributions that differ at the .20 level of significance represent different biological systems. This raises an interesting question: what α level should be used to test for "biological", rather than statistical, differences between two diameter distributions? To graphically illustrate this concept, consider Figure 12. The diameter distributions contained in this figure were not found to be statistically different at the .05 level by the two-sample K-S test. However, these two diameter distributions appear to be different due to the large number of trees contained in the 15- and 16-inch diameter classes of the ON plots. Thus, it may be that a significance level of .10 or .20 is more appropriate than the .05 level used in this study. More research is needed in order to determine the level of significance that should be used.

Responding Installations

For the ten installations with the largest volume growth responses (installations 22, 26, 64, 76, 89, 124, 137, 140, 148, and 155), the K-S test rejected the null hypothesis of no initial diameter distribution differences six times. Of these six installations, two were unthinned installations (22 and 26) and four were thinned installations (124, 137, 148, and 155). In five of the six installations, the 2N plots contained more large trees than the ON plots (installations 22, 26, 124, 137, and 155) although the ON plots actually contained more trees (Table 5). Thus, the presence of more large trees on 2N plots relative to ON plots in combination with a greater density on ON plots relative to 2N plots appears to have been responsible for anomalously large volume growth responses in five installations (22, 26, 124, 137, and 155). The situation described above (more large trees on 2N plots and a greater density on ON plots) can be summarized by saying that the 2N plots have a superior initial stand structure than the ON plots.

Adjusting for Differences in Stand Structure

These results indicate that site-specific response estimates may be spurious for those installations which were found to have significant differences in initial diameter distributions between treatments. Hence, it may be desirable to adjust response estimates when it is known that structural differences exist within an installation. Some preliminary work in this area was reported by the RFNRP (1974). Two methods of analysis were proposed to adjust for differences in stand structure between fertilized plots and control plots: adjustment of growth using covariance analysis and a method called "stand structure analysis". The second method utilized control plots to define unfertilized growth rates for each DBH class and then used these growth rates to project the growth rates of stems located in fertilized plots. The difference between actual fertilized growth rate and projected growth rate was taken to be the measure of response. This method was applied to data from two installations which were thought to be anomalous responders (RFNRP 1974). In both cases response estimates were thought to be improved by application of the method.

Neither of the methods mentioned above is completely satisfactory for rendering site-specific estimates of response. Covariance analysis does not adjust growth estimates for stand structure, and stand structure analysis will not yield valid results if heterogeneity of diameter distributions across treatments is great (Barclay and others 1982).

Methods which utilize pretreatment increment data have also been proposed for adjusting growth response when stand structure differences exist between treatments (Turnbull and others 1970; Ballard and Majid 1985). Unfortunately, increment data are not available for RFNRP installations.

Since nothing else was found in the literature relating to this type of estimation problem, the most apparent technique for use on RFNRP data is "stand structure analysis". However, as mentioned above, this technique can only be used if heterogeneity between treatments is not great. This presents a problem because of the subjective nature of the phrase "not great".

CONCLUSIONS

Analysis suggested that the two-sample K-S test was better to use than the two-sample chi-square test for evaluating the similarity of two diameter distributions. Tests were conducted at the .05 level of significance, a level that may be inappropriate to test for differences between two diameter distributions. Additional research is needed in order to determine the appropriate level.

Volume growth response was significantly correlated with initial volume difference for unthinned installations only. This partially explains some of the apparent low and high responders at the extremes of the fertilizer response range for those stands.

Ten of 91 installations had a negative volume growth response. The ON plots in each of these ten installations had a greater average volume than the 2N plots. Furthermore, the ON plots had diameter distributions that, in general, contained more trees in the larger diameter classes than the diameter distributions of the 2N plots. Two-sample K-S test results indicated that five of these ten installations had statistically different diameter distributions between treatments. Thus, it is highly probable that the negative volume growth responses associated with these five installations are a result of structural differences between treatments.

Heterogeneous diameter distributions may have also inflated some volume growth responses, since six of the ten installations which had the largest volume growth responses were found to have significant structural differences between treatments. In general, the 2N plots of these six installations contained more trees in the larger diameter classes than the ON plots and the ON plots had a greater density than the 2N plots.

Of the 91 installations analyzed, 42 were found to have heterogeneous diameter distributions between treatments as detected by the K-S test. Although thinning increased installation homogeneity with respect to initial volume difference, it did not appear to bring about parity in diameter distribution between treatments. Sixteen of the 31 thinned installations analyzed in this study were found to have heterogeneous diameter distributions across treatments.

These results indicate that site-specific response estimates based on treatment comparisons are suspect for those installations that were found to have significant differences in initial diameter distributions between treatments. In order to improve site-specific response estimates, "stand structure analysis" can be used. However, prior to using the method, further research is needed to determine the degree of diameter distribution heterogeneity allowable within an installation so valid results are obtained.

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Table 1. Average stand conditions, volume difference, volume growth response, K-S test result, and chi-square test result for each installation. Test result codes are as follows: 0 - accept null hypothesis and 1 - reject null hypothesis. Unthinned installations are numbered from 1 to 115. Thinned installations are numbered from 118 to 159. Tests were conducted at the .05 level.

Inst.	50-year Site Index (feet)	Age (years)	VDIFF (cu ft/A)	RESPONSE (cu ft/A/yr)	K-S Test Result	Chi-Square Test Result
1	115	35	903	60	0	0
5	103	30	64	82	0	0
7	134	40	1594	27	0	0
8	130	22	-310	30	0	0
10	121	30	-1655	-38	1	1
11	114	38	887	53	0	0
13	81	37	601	79	0	0
16	130	36	325	64	0	0
17	126	20	-756	54	0	0
20	145	27	1160	69	1	1
21	131	39	-2394	-31	0	0
22	126	46	1997	106	1	1
25	119	24	164	93	1	1
26	122	24	786	108	1	1
27	126	26	-800	11	1	1
28	137	22	-381	9	1	1
29	133	28	-720	23	0	0
30	137	27	-275	49	1	1
31	116	44	1266	63	0	1
32	124	39	-1531	79	0	0
34	138	28	625	85	0	0
37	126	42	-575	-15	1	1
46	124	9	17	82	1	0
47	101	42	136	89	1	1
50	86	30	-798	58	0	0
51	83	45	-541	56	1	0
53	123	22	391	49	0	0
54	104	36	665	83	0	0
55	95	39	307	40	1	0
57	135	30	619	46	0	0
59	99	35	-33	44	1	0
60	104	41	490	64	0	0
61	124	18	54	33	1	0
62	103	23	400	67	1	1
63	126	27	774	44	1	1
64	136	27	54	90	0	0
66	122	44	-843	28	1	1
67	90	37	-1702	14	1	1

Table 1. (Cont'd.)

Inst.	50-year Site Index (feet)	Age (years)	VDIFF (cu ft/A)	RESPONSE (cu ft/A/yr)	K-S Test Result	Chi-Square Test Result
68	132	30	-979	15	0	0
69	130	29	103	55	1	1
71	104	41	116	37	0	0
74	106	31	-124	-47	1	1
76	94	32	325	105	0	0
77	119	16	325	28	0	0
81	107	32	66	33	0	1
85	109	47	425	82	1	1
89	148	15	69	121	0	0
90	116	24	389	8	0	1
92	102	30	-623	-29	0	0
95	97	20	-653	26	0	0
97	111	31	593	50	1	0
98	125	38	-1215	-8	0	0
99	121	33	1774	15	1	0
101	119	24	-55	27	0	0
102	126	36	-876	52	1	1
103	105	19	-79	59	0	0
105	80	27	-204	38	0	0
113	117	23	-191	3	0	0
114	151	47	1443	16	0	0
115	124	42	-1111	-53	1	1
118	88	34	320	75	1	1
119	109	45	-422	46	1	1
120	123	14	-45	-10	1	1
124	128	41	355	95	1	0
125	120	29	59	27	0	0
126	142	30	-783	59	1	0
128	132	19	107	35	1	0
129	135	31	-118	82	1	0
131	137	29	457	31	0	0
134	92	34	-82	47	1	0
136	129	22	-103	-9	0	0
137	109	43	590	122	1	1
138	119	31	-51	-25	0	0
139	103	14	-107	7	1	0
140	131	20	-1	112	0	0
141	115	45	-363	70	1	0
142	115	13	-59	82	0	1
143	109	29	-62	26	0	0
144	127	20	74	58	0	0
145	114	26	-291	86	0	0
147	141	31	-98	60	0	0
148	103	35	-88	97	1	0

Table 1. (Cont'd.)

Inst.	50-year Site Index (feet)	Age (years)	VDIFF (cu ft/A)	RESPONSE (cu ft/A/yr)	K-S Test Result	Chi-Square Test Result
149	97	32	-202	65	0	1
150	99	48	314	57	1	1
151	70	19	59	65	1	1
152	124	42	333	79	0	0
155	111	30	599	146	1	1
156	107	27	43	46	1	1
157	115	32	410	28	0	0
158	113	45	-187	63	0	0
159	86	20	-34	62	0	0

Table 2: An example of a stand and stock table. The table contains stand structure information at two points in time: At the time of installation establishment (initial) and eight years later (final).

STAND AND STOCK TABLE -- STEMS, BASAL AREA, AND VOLUME BY DIAMETER CLASS

INSTALLATION 21 PERIOD: 1969-1977

	STEMS						BASAL AREA						VOLUME					
	INITIAL			FINAL			INITIAL			FINAL			INITIAL			FINAL		
DBH	000	200	400	000	200	400	000	200	400	000	200	400	000	200	400	000	200	400
2	0	3	0	0	0	0	0.0	.1	0.0	0.0	0.0	0.0	0	1	0	0	0	0
3	3	0	0	0	0	0	.2	0.0	0.0	0.0	0.0	0.0	6	0	0	0	0	0
4	0	7	0	0	3	0	0.0	.6	0.0	0.0	.3	0.0	0	15	0	0	8	0
5	3	30	13	0	3	0	.6	4.4	1.9	0.0	.5	0.0	18	137	64	0	16	0
6	13	13	17	0	10	0	2.8	2.6	3.5	0.0	2.1	0.0	98	86	126	0	77	0
7	47	40	57	10	7	13	13.9	11.2	15.9	3.1	1.7	4.0	509	392	608	123	65	167
8	37	43	50	30	17	13	13.4	15.4	18.1	10.3	5.9	5.0	509	557	722	420	233	215
9	37	40	67	30	33	33	16.4	17.8	30.4	13.3	14.3	15.0	636	659	1236	557	584	669
10	33	43	40	37	23	43	18.4	23.6	22.3	20.4	12.4	24.0	731	906	922	873	519	1079
11	20	23	40	13	30	20	13.3	15.5	26.9	9.1	20.3	13.7	543	611	1136	398	881	625
12	43	33	47	27	23	43	33.5	26.4	36.9	22.0	18.5	34.6	1378	1055	1584	979	817	1619
13	13	20	33	20	17	27	12.6	18.2	30.9	18.7	15.7	24.8	527	729	1333	840	702	1165
14	13	10	17	10	33	27	14.4	10.7	18.0	10.8	36.5	29.0	607	434	785	489	1634	1388
15	30	10	17	10	10	23	37.1	12.2	21.0	12.3	12.9	29.2	1568	500	930	562	584	1395
16	33	7	13	20	3	20	47.0	9.4	18.5	28.4	4.5	28.7	1995	396	824	1314	201	1373
17	13	7	3	17	20	10	21.0	10.7	5.0	26.4	32.2	15.7	899	453	227	1219	1487	761
18	7	7	0	33	3	17	11.9	12.1	0.0	58.8	6.1	29.7	521	519	0	2741	288	1458
19	0	3	0	20	7	7	0.0	6.7	0.0	39.8	12.9	13.5	0	288	0	1863	612	663
20	3	0	0	3	3	3	7.3	0.0	0.0	7.7	7.5	7.2	312	0	0	361	357	361
21	3	7	0	3	3	0	8.1	15.8	0.0	7.7	8.0	0.0	349	681	0	365	383	0
22	0	3	0	0	3	0	0.0	9.1	0.0	0.0	8.7	0.0	0	393	0	0	414	0
23	0	0	0	3	0	0	0.0	0.0	0.0	10.0	0.0	0.0	0	0	0	471	0	0
24	0	0	0	0	10	0	0.0	0.0	0.0	0.0	31.6	0.0	0	0	0	0	1522	0
25	0	0	0	3	0	0	0.0	0.0	0.0	11.1	0.0	0.0	0	0	0	528	0	0
SUMS	351	349	414	289	261	299	271.9	222.5	249.3	309.9	252.6	274.1	11206	8812	10497	14101	11384	12938

Table 3. Average volume growth responses to fertilization with 200 lbs N/A and maximum, minimum, and average volume differences for unthinned and thinned installations.

Installation Type	Average Volume Growth Response	Maximum Volume Difference	Minimum Volume Difference	Average Volume Difference
Unthinned	43 cu ft/A/yr	1997 cu ft/A	-2394 cu ft/A	8 cu ft/A
Thinned	57 cu ft/A/yr	599 cu ft/A	- 783 cu ft/A	20 cu ft/A

Table 4. Comparison of two-sample Kolmogorov-Smirnov (K-S) test results with two-sample chi-square test results for unthinned and thinned installations.

Installation Type	Number of times K-S test rejected null hypothesis	Number of times chi-square test rejected null hypothesis	Total number of Installations
Unthinned	26	22	60
Thinned	16	10	31

Table 5. Initial stems per acre (SPA) for 0N plots and 2N plots for installations with negative volume growth responses and the ten installations with the largest volume growth responses. K-S test result codes are as follows: 0 - accept null hypothesis and 1 - reject null hypothesis.

Response Type	Inst.	K-S Test Result	SPA of 0N plots	SPA of 2N plots
Negative	10	1	675	980
	21	0	351	349
	37	1	375	595
	74	1	463	318
	92	0	700	670
	98	0	350	345
	115	1	409	339
	120	1	530	680
	136	0	250	255
	138	0	265	270
Large Positive	22	1	412	355
	26	1	1350	955
	64	0	605	525
	76	0	1093	1390
	89	0	690	920
	124	1	191	154
	137	1	400	275
	140	0	295	270
	148	1	200	275
	155	1	315	250

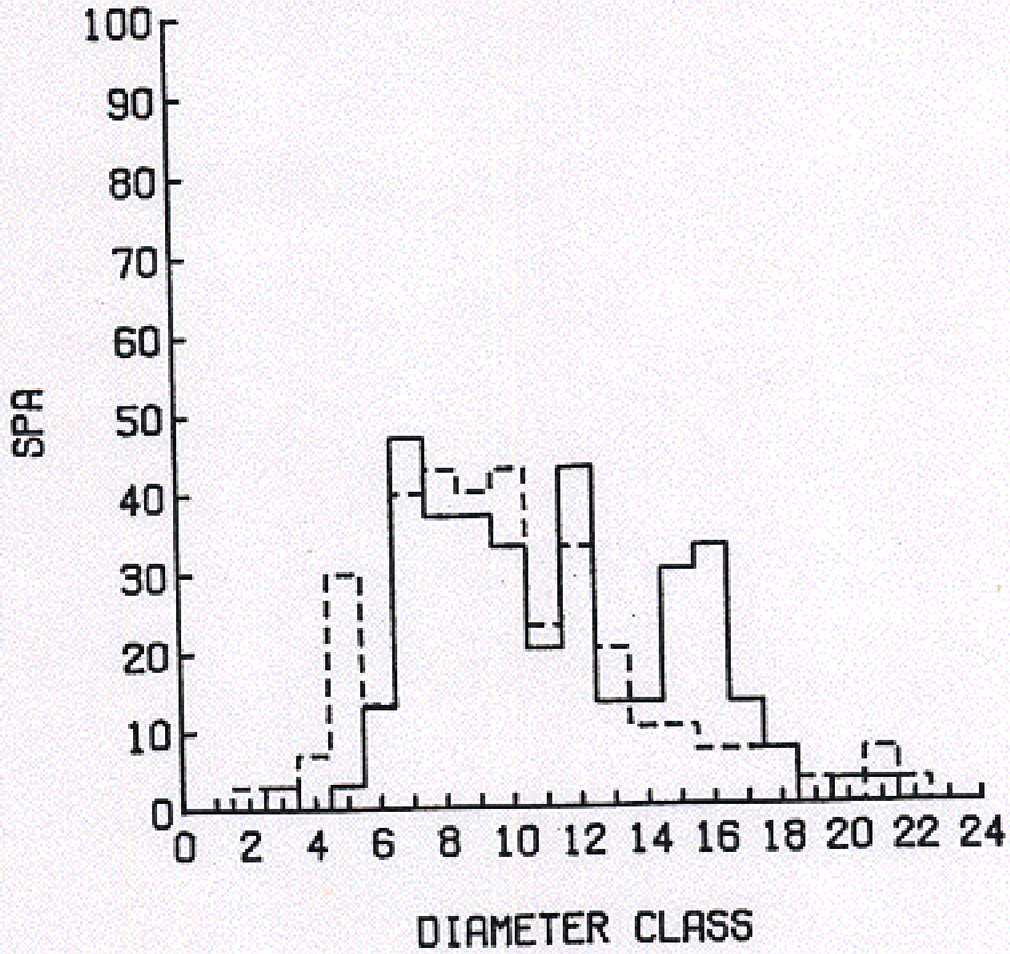

Figure 1. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 21.

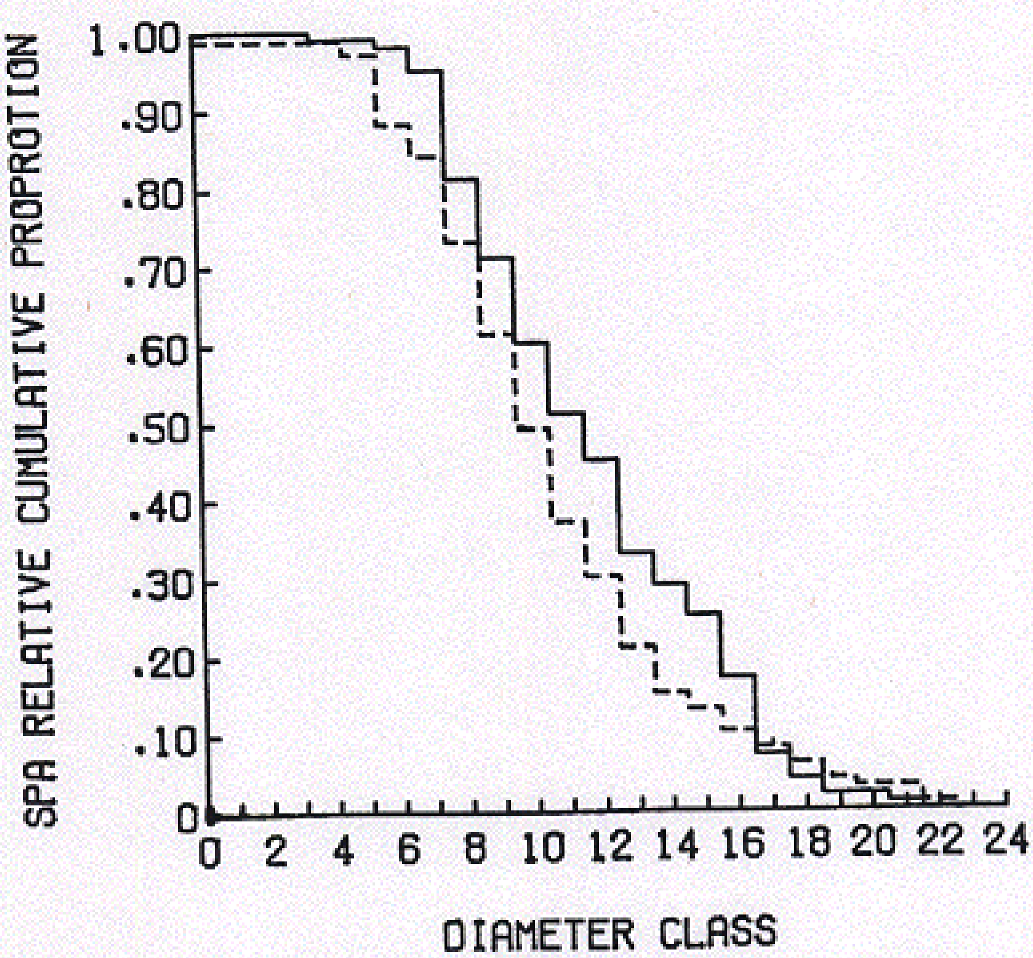

Figure 2. Relative cumulative proportion (RCP) graph of initial SPA for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 21.

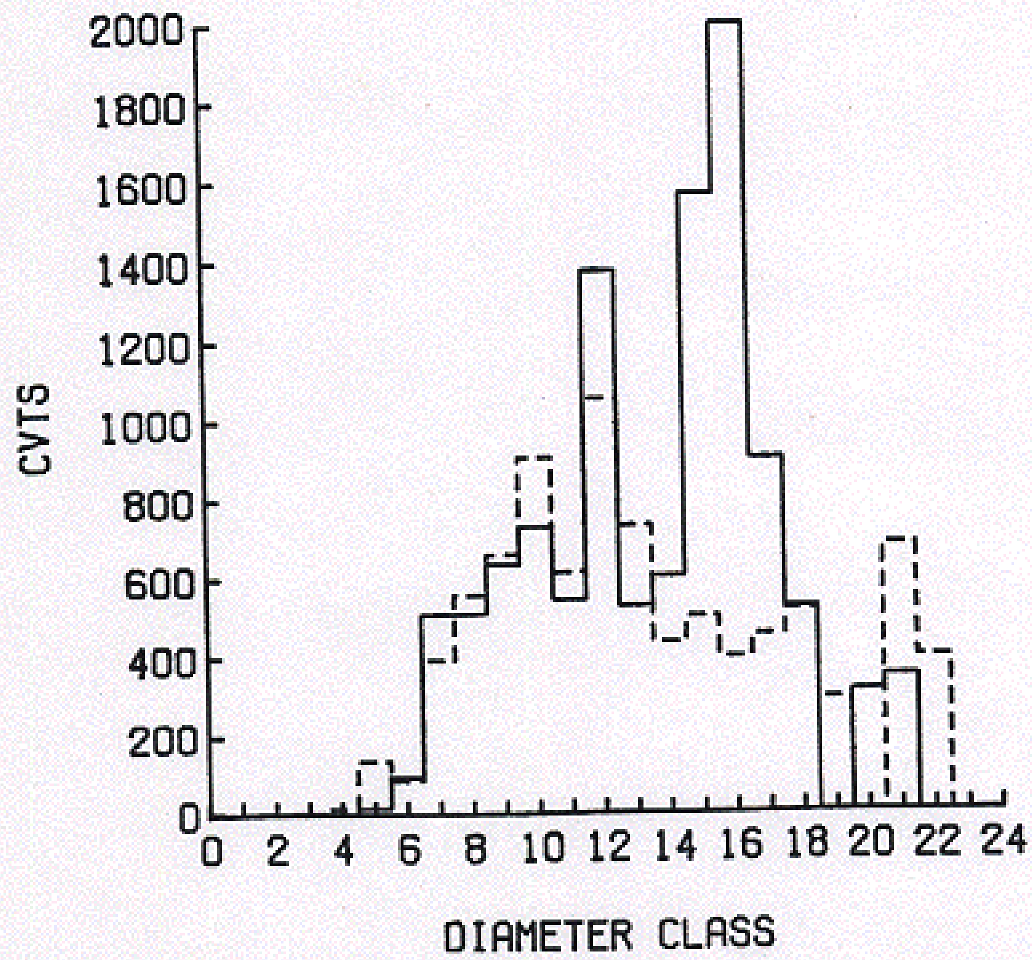

Figure 3. Histogram of initial CVTS by diameter class for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 21.

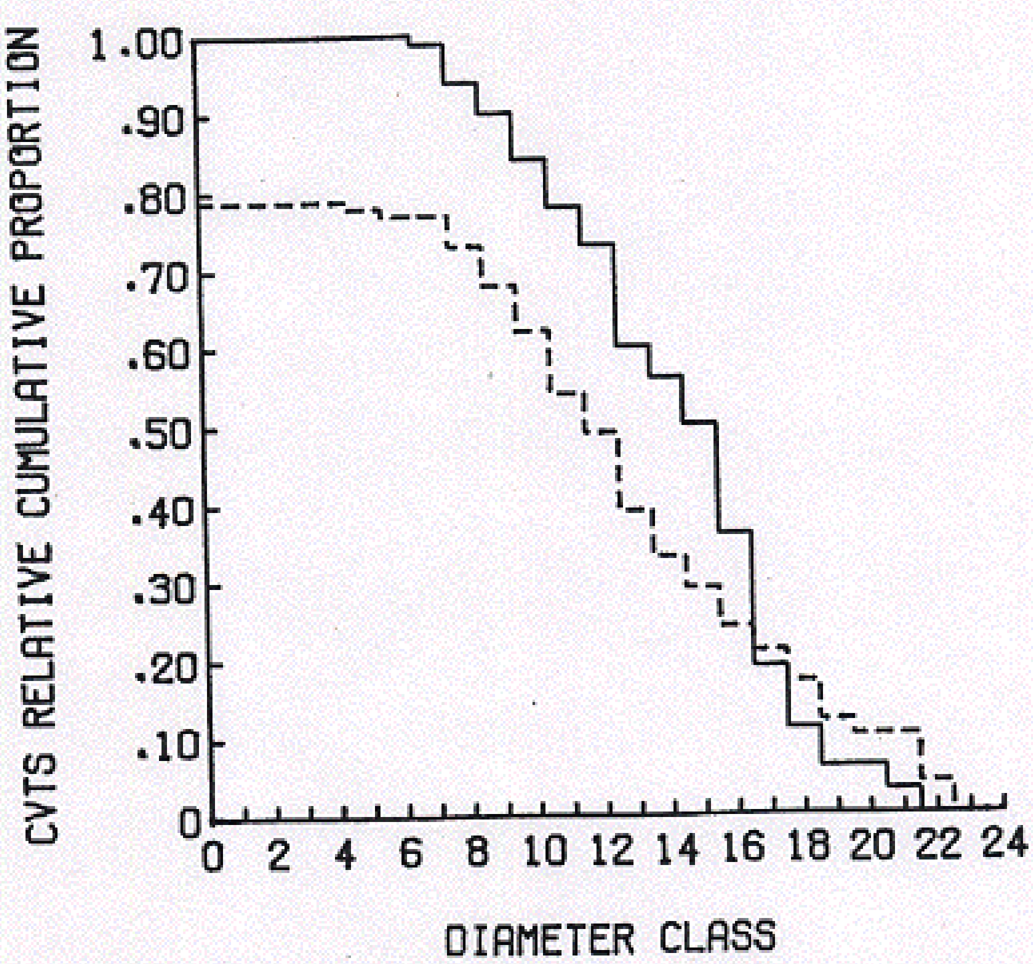

Figure 4. Relative cumulative proportion (RCP) graph of initial CVTS for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 21.

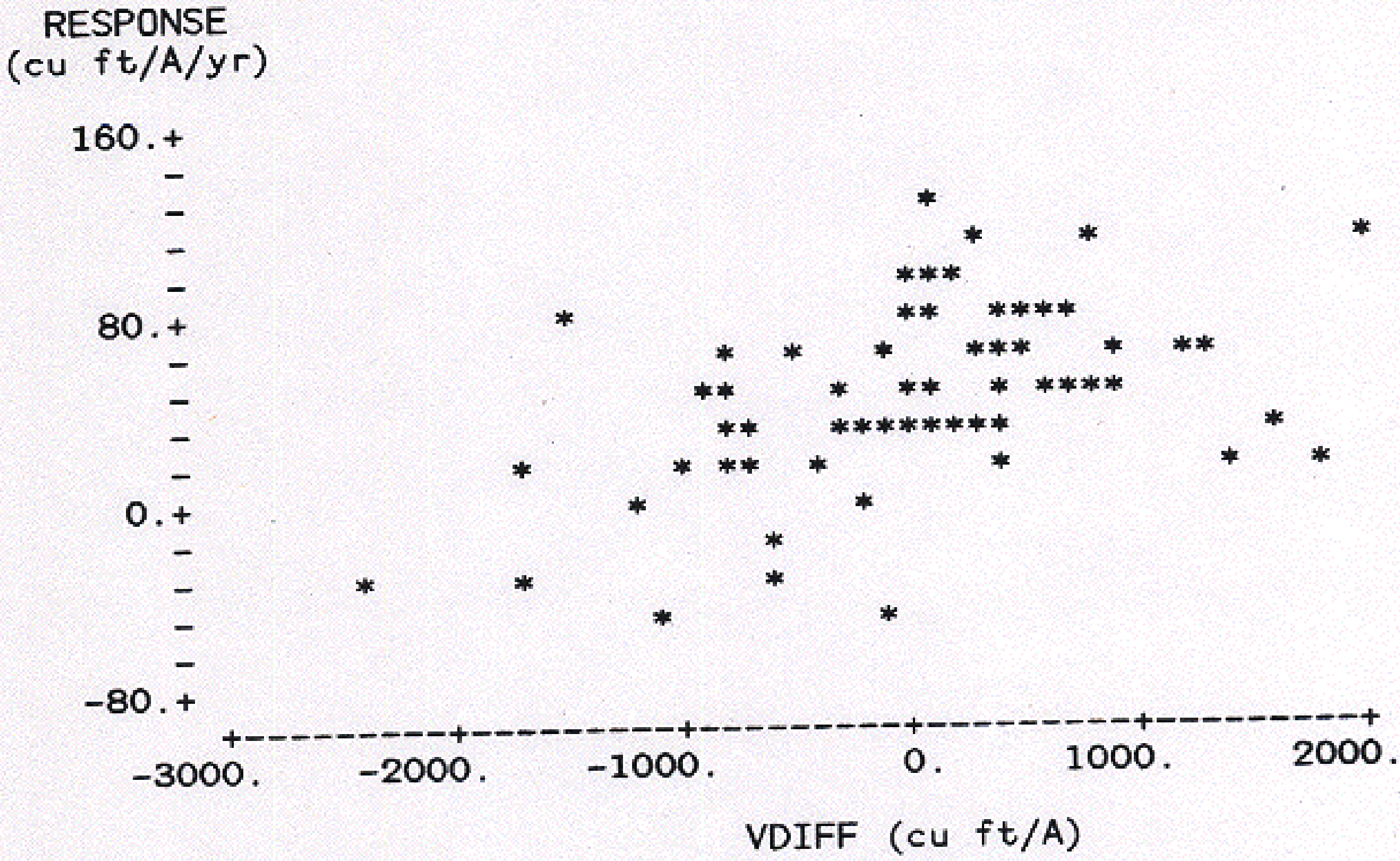

Figure 5. Volume response plotted against the volume difference between 2N plots and 0N plots for unthinned installations. The correlation between RESPONSE and VDIFF is .469 (df = 58, $p < .01$).

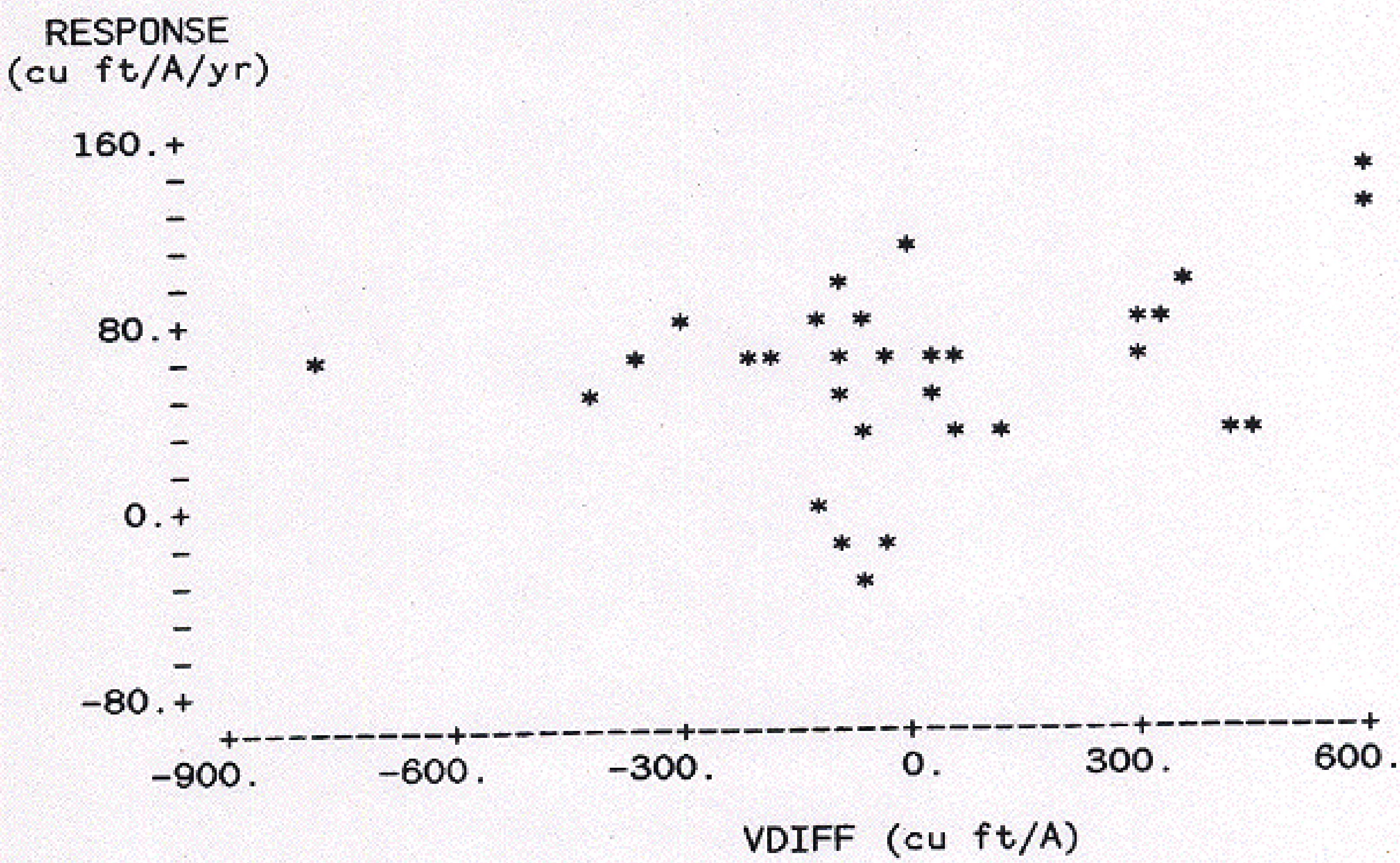

Figure 6. Volume response plotted against the volume difference between 2N plots and 0N plots for thinned installations. The correlation between RESPONSE and VDIFF is .265 (df = 29, $p > .05$).

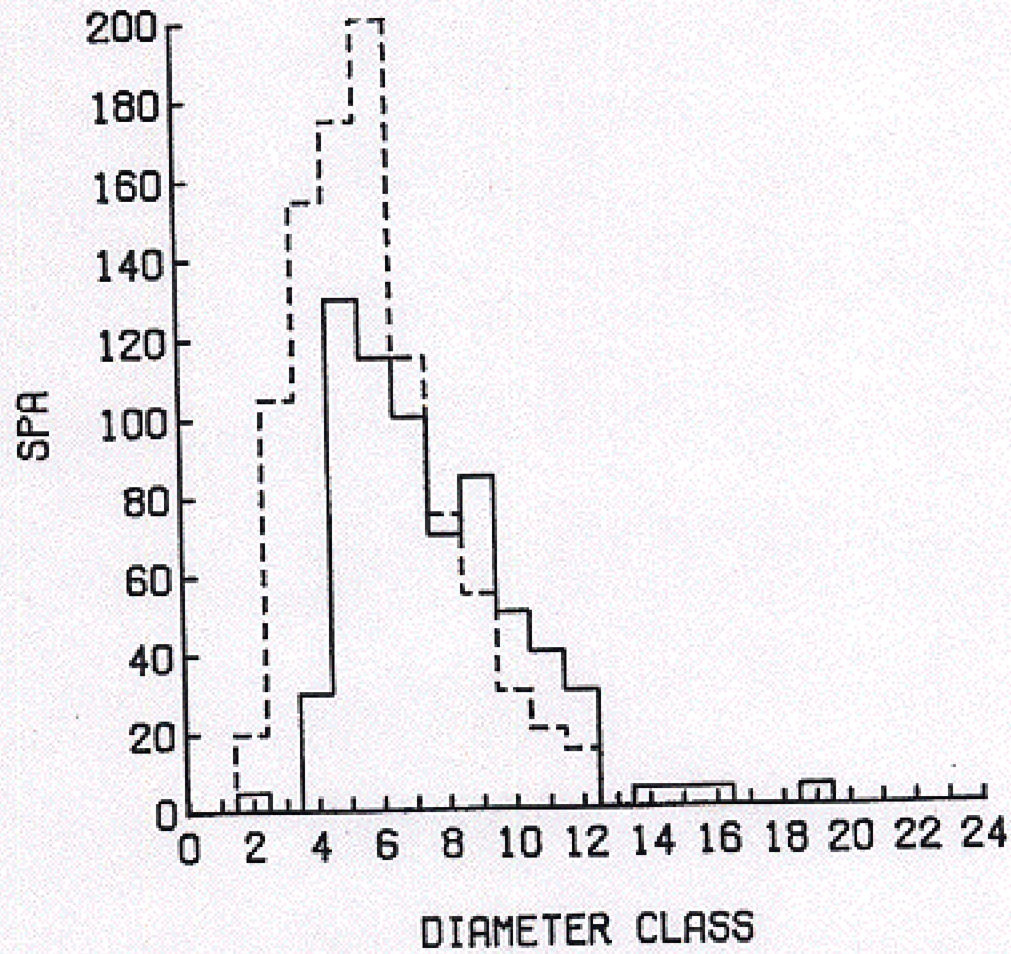

Figure 7. Diameter distributions for combined 0N plots (solid line) and combined 2N plots (dashed line) for installation 10. These diameter distributions were found to be significantly different ($p < .05$) by a two-sample K-S test.

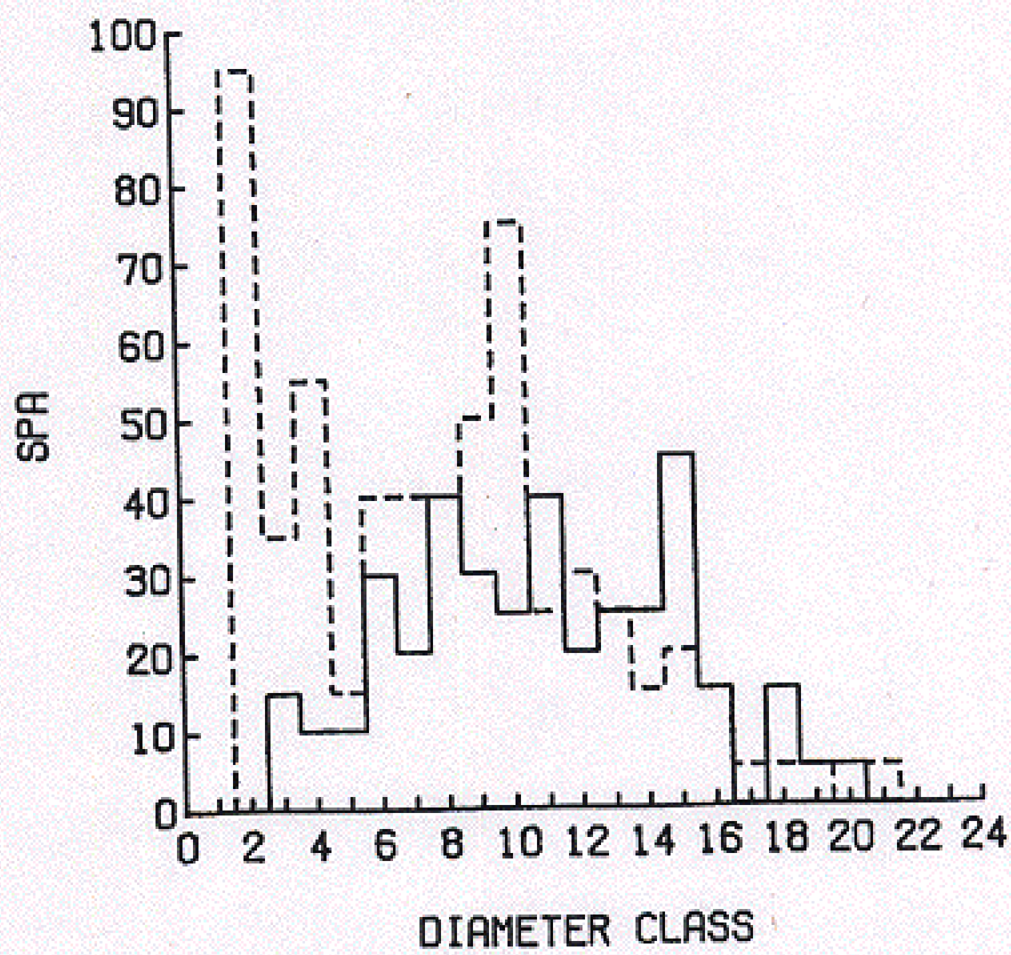

Figure 8. Diameter distributions for combined 0N plots (solid line) and 2N plots (dashed line) for installation 37. These diameter distributions were found to be significantly different ($p < .05$) by a two-sample K-S test.

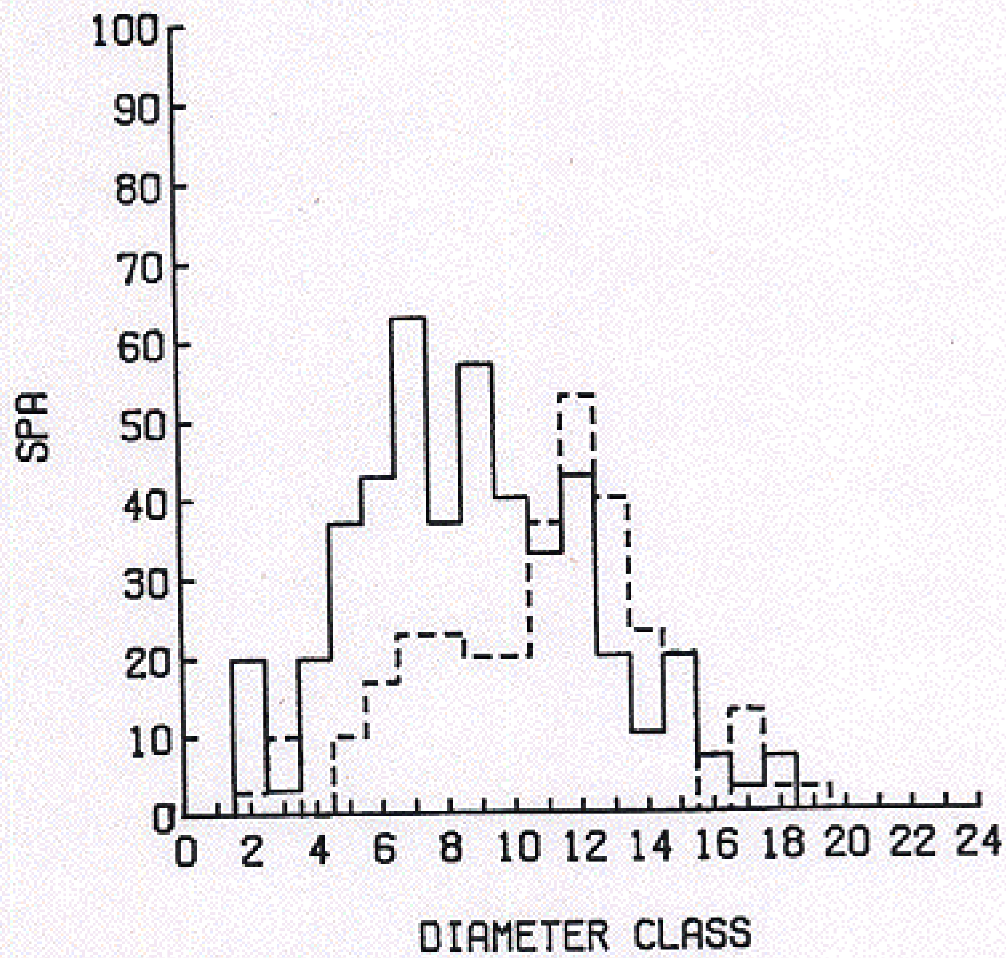

Figure 9. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 74. These diameter distributions were found to be significantly different ($p < .05$) by a two-sample K-S test.

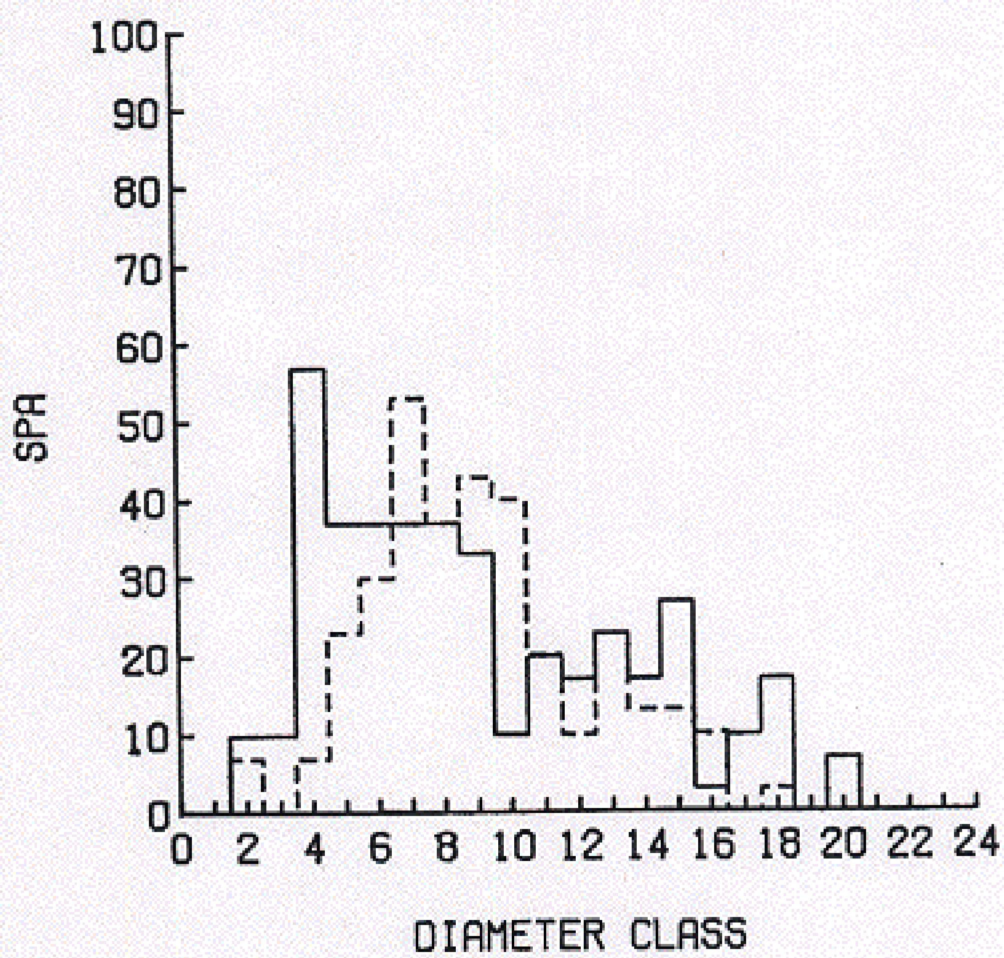

Figure 10. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 115. These diameter distributions were found to be significantly different ($p < .05$) by a two-sample K-S test.

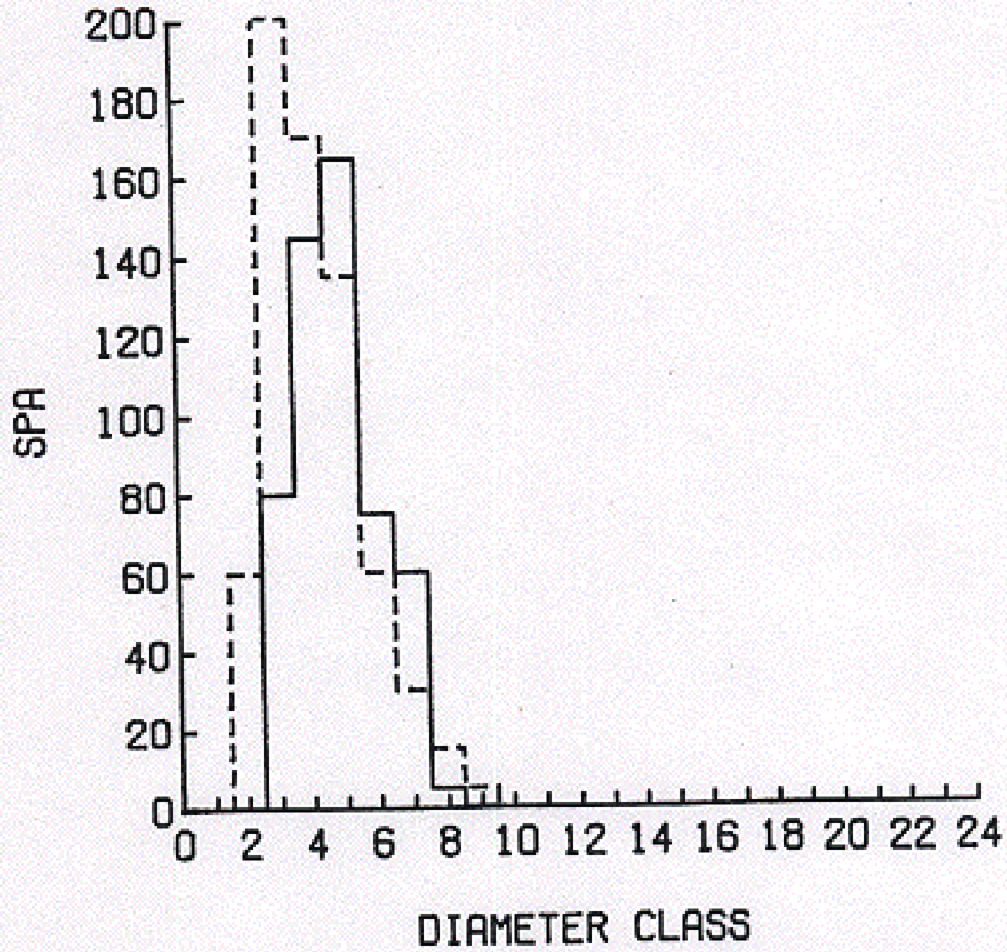

Figure 11. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 120. These diameter distributions were found to be significantly different ($p < .05$) by a two-sample K-S test.

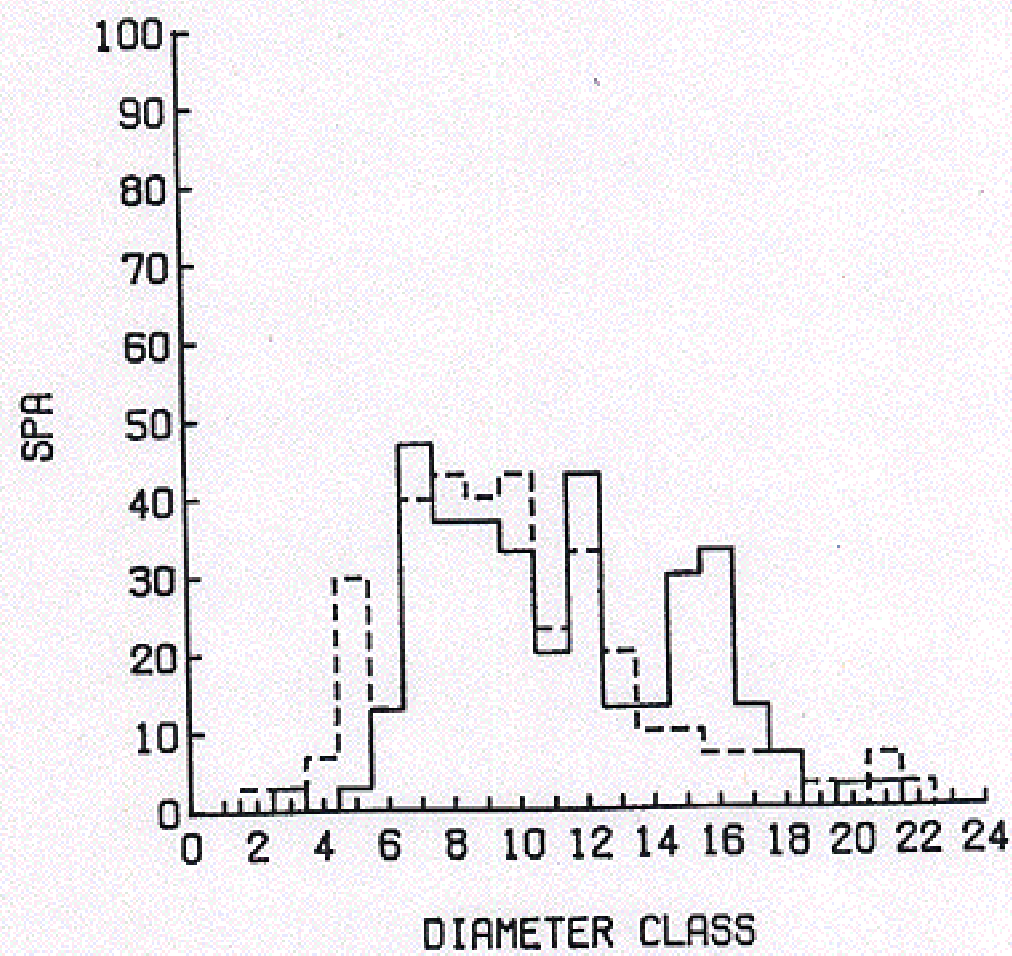

Figure 12. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 21. These diameter distributions were not found to be significantly different ($p > .05$) by a two-sample K-S test.

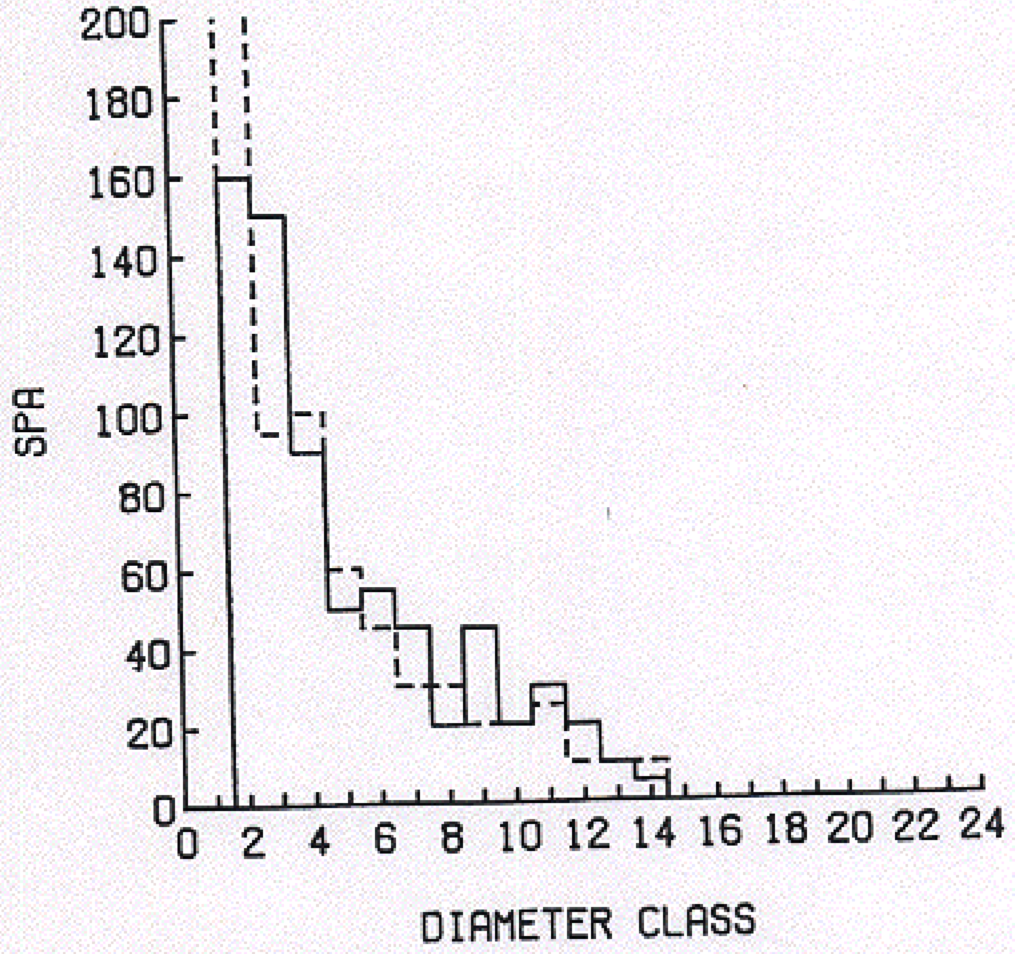

Figure 13. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 92. These diameter distributions were not found to be significantly different ($p > .05$) by a two-sample K-S test.

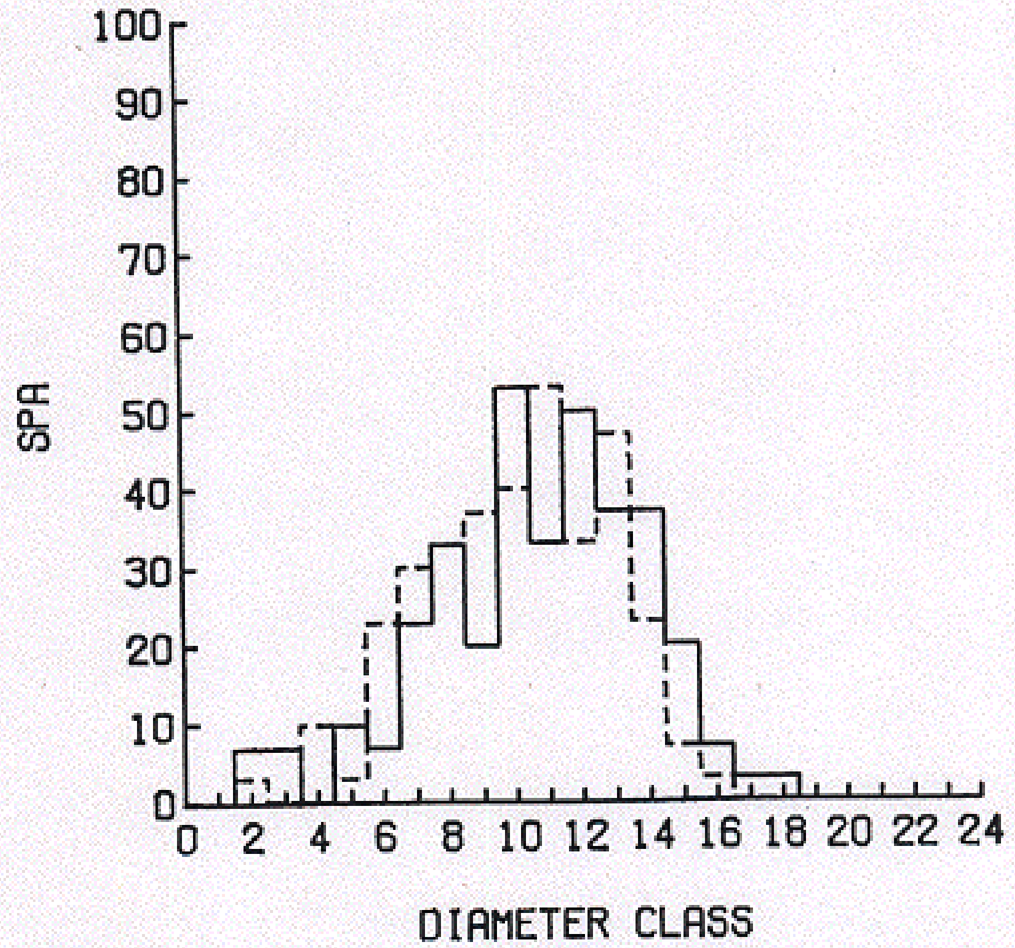

Figure 14. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 98. These diameter distributions were not found to be significantly different ($p > .05$) by a two-sample K-S test.

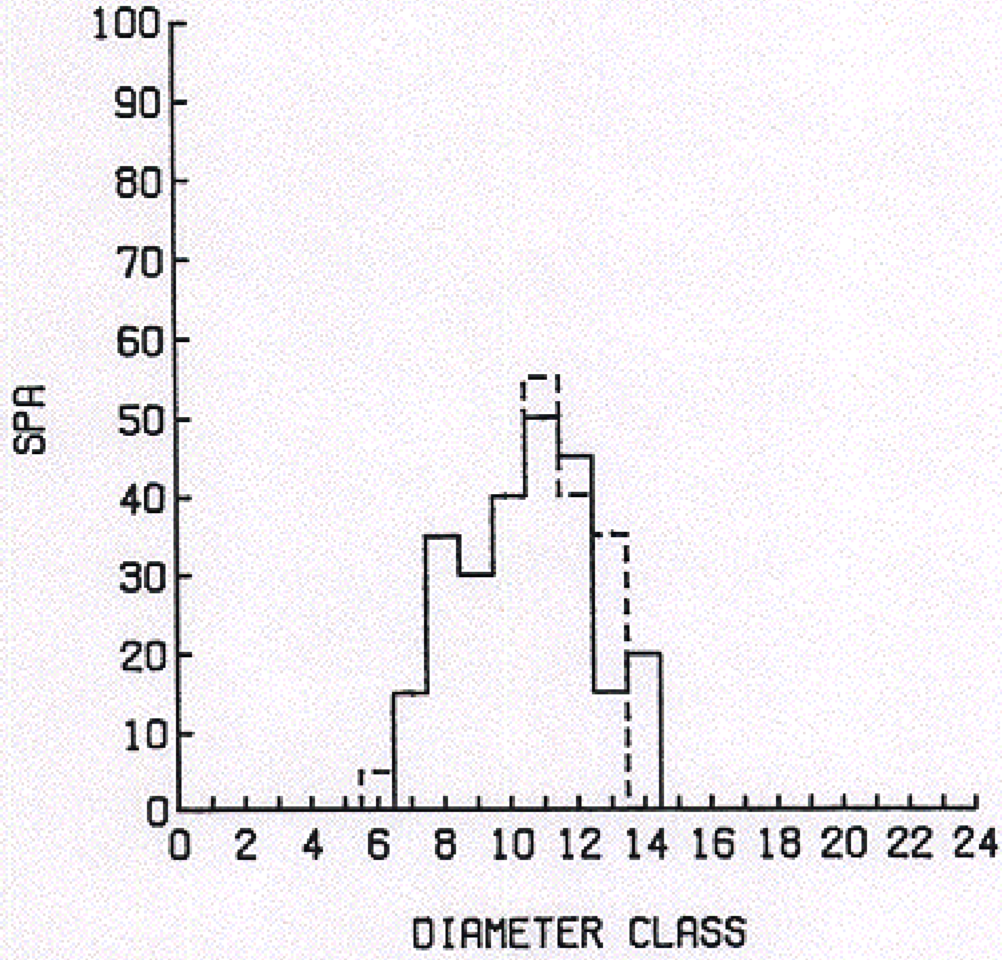

Figure 15. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 136. These diameter distributions were not found to be significantly different (p > .05) by a two-sample K-S test.

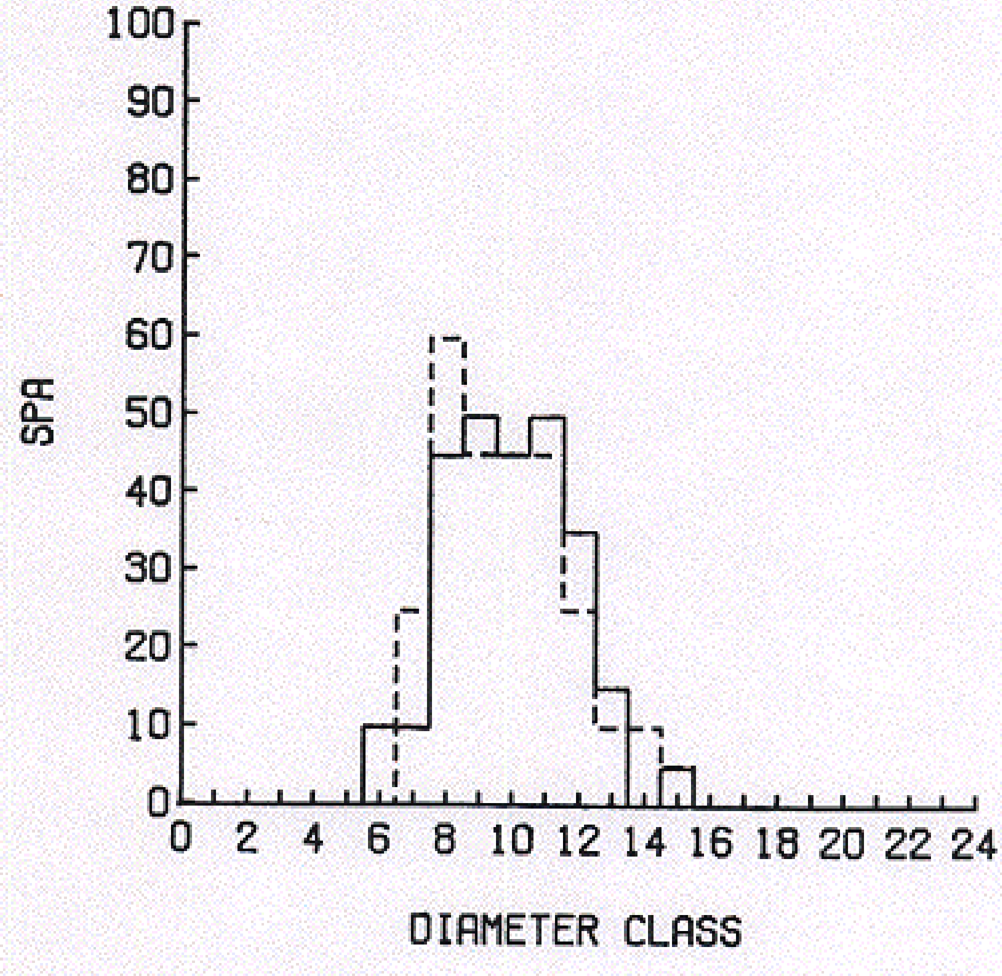

Figure 16. Diameter distributions for combined ON plots (solid line) and combined 2N plots (dashed line) for installation 138. These diameter distributions were not found to be significantly different (p > .05) by a two-sample K-S test.