Sequential Sampling of Ribes Populations in the Control of White Pine Blister Rust (*Cronartium ribicola* Fischer) in California

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U S. FOREST SERVICE RESEARCH PAPER PSW- 36

Pacific Southwest
Forest and Range Experiment Station
Berkeley, California

1966 Forest Service - U. S. Department of Agriculture

Offord, Harold R.

1966. **Sequential sampling of ribes populations in the control of white pine blister rust *(Cronartium ribicola Fischer)* in California.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 14 pp., illus. (U.S. Forest Serv. Res. Paper PSW-36)

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The Author

HAROLD R. OFFORD is a consultant to the Station, where he served as chief of the division of forest disease research from 1956 until his retirement in 1964. Native of Toronto, Canada, he earned bachelor's and master's degrees in biochemistry at the University of British Columbia. Much of his career has been devoted to work on methods of controlling white pine blister rust and other forest diseases, with various agencies of the U.S. Department of Agriculture, including the Bureau of Plant Industry, Bureau of Entomology and Plant Quarantine, and California Region and Berkeley Experiment Station of the Forest Service.

Acknowledgments

The advice and help of the following personnel of the U.S. Forest Service who provided statistical or field time to the evaluation of this study is gratefully acknowledged: Austin A. Hasel, for early statistical help in Washington, D.C. (1956); Roy Blomstrom and Neil MacGregor, for field trials in California (1956, 1964) ; Jerry Dieter, Marion Holt, W. Jensen, and John Mitchell, for pilot field tests in California (1964); Lyle Anderson, George Harvey, and Benton Howard, for field assistance in Oregon (1957) ; F. N. David, C. J. DeMars, R. M. Miller, W. G. O'Regan, G. Schwarzbart, and D. A. Sharpnack, for statistical criticism and suggestions (1963-1965) ; and Allen M. Weil, who wrote the Fortran program for the IBM 7094 computer (1964-1965).

The control of white pine blister rust (*Cronartium ribicola* Fischer) is a widespread and well known problem in forested areas throughout the United States. In California, as in other white pine regions, control is based on the suppression of the alternate host plants--native currants and gooseberries (*Ribes* spp.)--to prescribed population levels. The success of this control effort is usually determined by a formal survey which provides maps and data to show the size and distribution of the residual ribes population. Local climate and plant associations determine whether the rust hazard is high, average, or low. And this rust hazard in turn sets the tolerable limits for the incumbent population of ribes.[1] Administrative inspections, or combinations of such inspections and formal surveys, also are used in appraising the need for control work or its effectiveness.

In forest disease control work in which a distribution map of host or pathogen is available, or not needed, sequential sampling can minimize survey effort. And in an orderly and statistically useful way, it can allow for increased sampling in accord with control needs.

This paper reports on a study in which a sequential sampling plan was developed for surveying ribes populations in California. The cost and usefulness of this plan are compared with those of the standard survey method now in use. The term "cost" as used here means the time needed to do the survey and does not imply an economic analysis of all factors involved. Advantages of sequential sampling for ribes surveys and some of its limitations also are described.

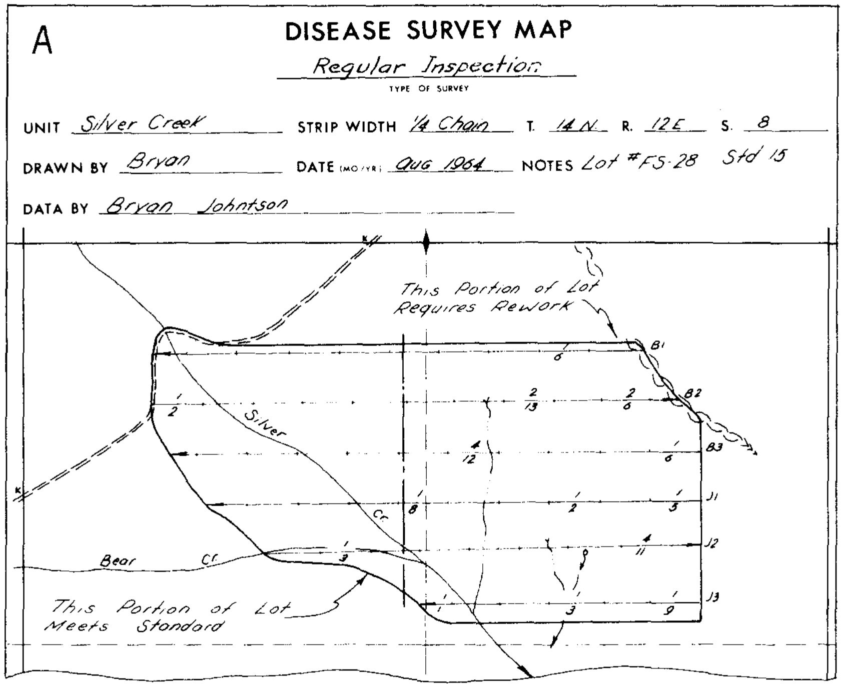
The sequential plan herein described is based on ribes survey records and control standards in California and may need to be modified for use elsewhere. There are still several unresolved theoretical questions that relate to the efficient field use of sequential sampling. These are now being studied by statisticians at this Station. Nevertheless, studies to date indicate that sequential sampling is probably at least as good as the sampling method now in general use. Therefore, computer programs have been designed and tested to produce sequential plans suitable for further tests under a variety of field conditions.

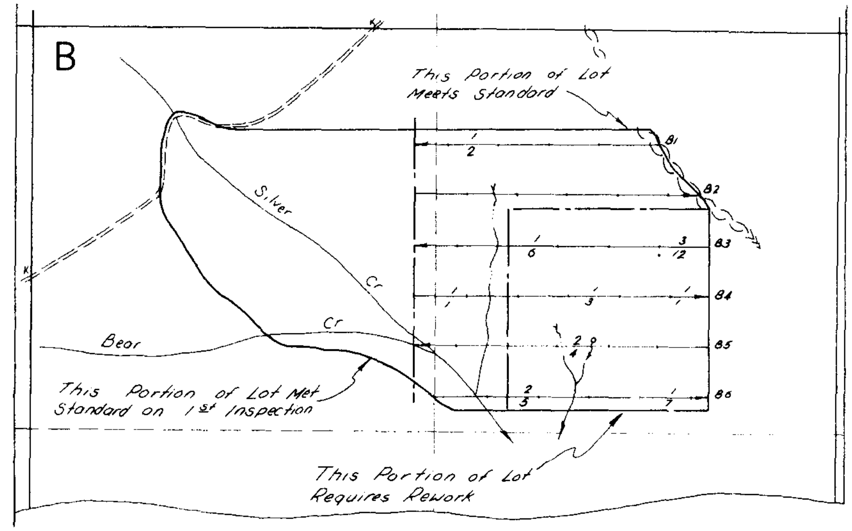
Ribes Surveys

Cost and efficiency of ribes surveys has been the subject of intense interest and considerable study since the control work was formalized in the early 1930's. Harris (1941) described field methods used for sampling ribes populations, giving special attention to work in sugar pine forests of California. Much of the background and detail on studies subsequent to his publication is in unpublished reports not readily available for reference. In 1964 the California Region of the U.S. Forest Service completed a revised training aid for surveymen entitled "Ribes Surveys in California." This publication effectively brings up-to-date procedures for the planning and conduct of this work.

Ribes survey, or "checking" as it has been traditionally called in blister rust control work, is an integral and continuing part of the total control job. In California three types of checking are recognized. In control parlance they are known as *advance, regular,* and *post checks. Advance check* shows the distribution, number, and size of host plants as an aid in the planning of eradication work. *Regular* or *inspection check* (fig. 1) determines if a specific blister rust control unit has been worked to prescribed control standards. *Post check* appraises the status of the ribes population and ribes regeneration, and from this the

[1] Refers collectively to native currants and gooseberries. *Ribes* spp.





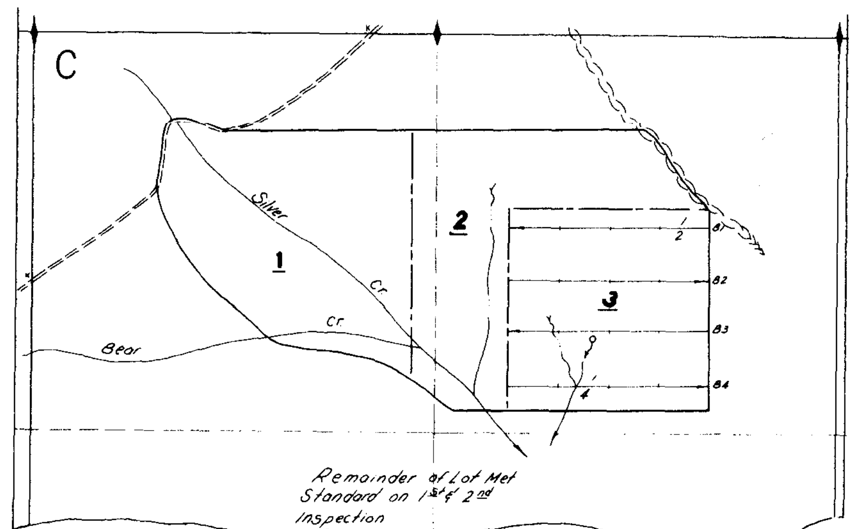


Figure 1.--*Line transects of regular check are spaced at uniform intervals, run in cardinal directions, and show the total number of ribes hushes (numerator) and linear feet of live stem (denominator) on each consecutive 5-chain transect. The entire lot (A) may meet control standards in progressively smaller segments (B and C).*

need for and the timing of another eradication job. All of these checks employ the systematic continuous strip transect plot.

Essentially the current approved regular check in California samples about 5 percent of the area under examination. For each block of land (or contract lot) continuous strips $^{1}/_{4}$-chain wide ($16^{1}/_{2}$ feet), and spaced at 5-chain intervals, are run across contours in cardinal directions. Ribes bushes and the linear feet of live stem (FLS) are counted and measured as found, allocated to successive 5-chain transect, and later summarized on a checker's map to show the location of the sampling strips and the ribes population (fig. 1).

The present strip-transect survey (fig. 1) has served control needs effectively for more than 30 years. This checking method was designed to maximize information on the distribution of ribes within the control area. For acceptance in the control program any alternative method must be more economical than the regular method at a fixed level of reliability or must provide higher levels of reliability for common levels of cost. This paper reports evidence suggesting that where a ribes distribution map is already available or not needed, and where systematically acquired ecologic data are not essential to the control decision, checking objectives can be achieved economically by random plots sequentially evaluated.

With some modification for regional conditions and control objectives, similar types of ribes surveys are made in all white pine areas of the United States where blister rust control work is being undertaken. Recent estimates from California show that the costs of checking are about 20 percent of the total costs of blister rust control. Thus, any improvement in the cost or efficiency of checking would find wide application.

Sequential Sampling

Theory and Use

Sequential analysis provides a method of statistical inference that does not depend on a sample of fixed size. Randomly chosen sampling units are examined until the accumulated measurements fall above or below prescribed class levels. Theory supporting sequential analysis was devised by Wald (1943, 1945, 1947) from research with the Columbia University Statistical Research Group (1945). Independently Barnard (1944, 1946) recognized the merits of sequential sampling and the possibility of reducing costs by minimizing sample size. Their publications--along with Wald's (1947) text on sequential analysis--triggered intense interest in the practical uses of sequential sampling in industry and in biological surveys which can be categorized as quality control problems.

In forest surveys the regularly-spaced plot or transect often has been strongly favored over randomly chosen plots. Among the cogent reasons for this are: (a) the simplicity and ease of locating and mapping the plots or transect lines, and (b) the desire to obtain representative coverage of what may be a variable pattern of trees, shrubs, and other vegetation over the land area. Statisticians concede the validity of the first but not the second thesis; they point out that sampling errors either are not known in the case of regularly spaced plots, or are computed incorrectly by theories and formulae based on random selection. The testing and use of sequential sampling in forest surveys has without doubt been restricted by the natural bias of foresters against randomly selected plots--especially in rough or brushy terrain, which is difficult to walk over. Also, depending upon the survey objective, the ecologic variations within a block of land may strongly dispose against chance location of plots. Freese (1962) and Smith and Ker (1957) have summarized essential aspects of sampling in relation to forest problems.

The impact of plot size and shape and the number of plots per unit of land area on the usefulness of any random or systematic sampling plan has long been recognized, but not satisfactorily worked out.[2] In the concluding section of this report, field comparisons between standard and

[2]Mathematical statisticians F. N. David, of the University of California, and W. G. O'Regan, of the Pacific Southwest Forest and Range Experiment Station, are now studying theoretical aspects of this problem. One of the more thorough field studies of this problem was reported April 16, 1942, by J. N. Mitchell. G. J. Taylor, C. W. Fowler, and S. D. Adams, in an unpublished blister rust report (California) titled "The forty-acre checking experiment."

sequential surveys are based on the use of plots of similar size and shape (5 chains long by 1/4-chain wide).

The great advantage of sequential sampling over systematic sampling is the smaller sample needed by sequential procedures to make decisions on quality of lots that are either extremely good or extremely bad. In forest surveys, for example, systematic sampling by fixed-sample size requires a large amount of time to count or measure the plant or the pest where populations are high, and in addition permits inadequate attention where populations are low. Table 1 summarizes other factors pertinent to the merits of well-known and widely used sampling schemes.

Because of uncertainty about variation in the distribution of plant and animal populations, biologists lagged behind manufacturers in testing and applying sequential sampling to their operations. Evans (1953) analyzed some factors that affect contagious distributions in plant and insect populations. He concluded that Neyman Type A and negative binomial expressions were generally the most applicable to sampling of plant and insect populations. Oakland (1950), Stark (1952), Morris (1954), and Waters (1955) were among the first of the biologists to devise sequential plans for inspection and survey. Their experience confirmed conclusions of the Columbia University Statistical Research Group (1948) about the usefulness of sequential sampling.

More recent applications of sequential sampling to forestry problems are those by Smith and Ker (1958) in reproduction surveys, Dick (1963) in forest stocking, and Kozak (1964) in damage by cone and seed insects in Douglas-fir. All of these workers showed that sequential procedures provided meaningful answers to questions of quality of work at about half the cost of other sampling methods.

Table 1.--*Factors influencing choice of type of sampling*[1]

Factor	Single sampling	Double sampling	Sequential sampling
Protection against rejection of good inspection lots and acceptance of bad inspection lots	Practically equal		
Average number of items inspected per inspection lot	Most	Intermediate	Least
Variability in number of inspected items from inspection lot to inspection lot	None	Some	Some
Sampling costs when samples can be drawn as needed	Most expensive	Intermediate	Least expensive
Sampling costs when all samples must be drawn at once	Least expensive	Most expensive	Intermediate
Estimation of average inspection-lot quality (if estimate is based on large number of inspection lots, differences from one type of sampling to another may not matter)	Most precise	Intermediate	Least precise
Training inspectors to use plans	Easiest	Intermediate	Hardest
Psychological: 'give inspection lot more than one chance'	Worst	Intermediate	Best

[1]Source: Columbia University Statistical Research Group. 1948, p. 96.

Sequential Plans for Ribes Surveys

My interest in sequential sampling of ribes populations in the Western States dates from the early 1950's, when relaxation of wartime security gave access to the classified research of Wald (1943) and others. The first sequential plan for ribes survey was field-tested in 1956 on the Sequoia National Park, California, and in 1957 on the Rogue River National Forest, Oregon. This plan, based on a negative binomial distribution, was developed from highly reliable data on the number of ribes and their size in linear feet of live stem from a 10-acre study plot at Cow Creek, Stanislaus National Forest in central California. To compare theoretical and actual ribes count for Poisson, Neyman contagious, and negative binomial distributions, Wadley (1950) used these same ribes data from the 10-acre study plot at Cow Creek, as well as similar ribes data from five other study areas in California and Idaho. Using the chi-square test, he showed that the negative binomial gave much the best fit in all, six examples. Fracker and Brischle (1944) had previously used these same sets of field data to compare actual total ribes with those of fitted Poisson and Neyman contagious type distributions. They concluded that the best fit was a mixed distribution of about one-third Poisson and two-thirds Neyman contagious. They did not report on the negative binomial distribution in their study.

As the following comparisons from these first field trials show, the "sequential" sampling method provided answers of similar significance (in the blister rust control sense) to the "regular" method and at a much lower cost. The sequential plan of the 1956 and 1957 field tests was based on bush counts and made use of per acre acceptance limits of two bushes or less and rejection at levels above two bushes.

In October 1956, Sequoia National Park T. 15 S., R. 29 E., sec. 26, N $^1/_2$, ribes data from a post-check unit of 320 acres, a comparison showed:

- Sequential mean of 0.50 ribes per acre (8 man-hours of checking time).
- Regular mean of 0.67 ribes per acre (26 man-hours of checking time).

Also in October 1956, Sequoia National Park T. 15 S., R. 30 E., sec. 31, NE $^1/_4$, a comparison of 160 acres of supposed blockout showed:

- Sequential--blockout OK (5 man-hours of checking time).
- Regular--blockout OK (21 man-hours of checking time).

In July 1957. a comparison test run on a 160-acre post-check unit on the Rogue River National Forest showed:

- Sequential mean 1.2 ribes per acre ($6^1/_3$ man-hours of checking time).
- Regular mean 1.5 ribes per acre (35 man-hours of checking time).

These encouraging results clearly justified further study of the distribution characteristics of ribes populations on a broader sample basis than was done in 1956 and 1957. All subsequent field tests used sequential plans derived from feet of live stem (FLS) measurements rather than bush counts to conform with accepted biological needs of the control program and with criteria used in the regular checking method.

A Fortran program devised by Kozak and Munro (1963), and modified in 1964 by A. M. Weil and D. A. Sharpnack of the Forest Service for the IBM 7094 computer, was used to compare the goodness of fit for normal, Poisson, binomial, and negative binomial distributions of ribes for some 61 blister rust control lots in the Sierra Nevada of California. Statistics derived in 1956 and 1957 from the Cow Creek plot, from Sequoia National Park and Rogue National Forest tests, and those from 61 different lots coded for computer calculation, all suggest that the negative binomial distribution provides the best fit both by chi-square test and by inspection of the tabulated field data.

There is some question about the suitability of the chi-square test where as much variance and overdispersion exists as in the classes of ribes making up the populations in the different control units. Nevertheless, statistics for the mean, the class frequency, and variance of the 61 lots indicate that most individual lots generally follow accepted theory of the negative binomial $(q-p)^{-k}$ as described by Fisher (1941) and others.[3] The distribution curve for class numbers of ribes bushes or linear feet of live stem per sampling unit is strongly skewed towards the zero side of the mean and would be described in general terms as unimodal. In nearly all cases the variance was more than five times the mean.

[3] Anscombe (1949, 1950). Bliss (1953), Bliss and Owen (1958), Fisher (1953). Kozak (1964), Oakland (1950). Wadley (1950), Waters (1955).

In white pine forests the distribution of ribes, as shown by actual survey maps and by field inspection, takes on the following characteristics: After the incumbent population has been disturbed by one or more eradications, the residual population of the whole block as measured on 1/16-, 1/8-, or 1/10-acre sampling units (plot size commonly employed in surveys or in field studies) shows a disproportionate and increasing number of zero-count plots and a steadily decreasing number of plots having counts of one, two, three, and more of the items being recorded. This observation is consistent with the known distribution of ribes in wildland areas, and also with the fact that eradication workers tend to find and remove a much higher portion of the large than of the small bushes. The negative binomial is a discrete distribution and feet of live stem (FLS) is a continuous variable. But sequential plans used in all field trials comparing sequential and regular sampling of ribes (including preliminary trials of 1956 and 1957 in California and Oregon and those of 1964 on the Lassen and Shasta National Forests) were based on the assumption that the negative binomial provided a useful and reliable expression of the true distribution of ribes populations on areas that have had at least one working.

From these preliminary field trials and from theoretical considerations just reviewed, the negative binomial has been used in this study as the most useful approximation of the manner in which residual ribes populations on worked areas are apt to be distributed.

Sequential Graphs for Prescribed Control Purposes

Sequential sampling is applicable to surveys that can be based on prior knowledge of the distribution of the item to be measured and on agreement on meaningful class distinctions for the accept (pass) and reject (fail) decisions. Such information is available for evaluating ribes surveys. Blister rust control maps and checking records of the past 30 years provide a vast reservoir of quantitative data on the size and distribution of ribes populations in sugar pine forests of California. These records show the distribution of ribes bushes and their live stem equivalents after one or more eradication jobs have been completed. And much specialized knowledge on the ecology of ribes in California is available from the studies of Quick 1954). Other white pine regions of the country have similar knowledge about ribes populations. Thus, a sequential plan for ribes survey can be devised that is specifically adapted to populations of known parameters and to prescribed standards of rust control. To facilitate development of a usable sequential plan, the field data reported in this paper are related to the so-called regular check and to blister rust control standard 15 and standard 60.

In standard 60 control work, the contract lot is accepted if the regular 5 percent check shows 60 or less feet of ribes live stem (FLS) per acre; it is rejected if the check shows 61 or more FLS per acre. Standard 15 has a similar meaning as to acceptance or rejection. For blister rust control purposes, standard 15 means that the local rust hazard is more serious than that in the standard 60 situation, and that the ribes population in the case of the standard 15 must be reduced to a lower and biologically safer level.

Data from regular survey maps (fig. 1) for 24 standard 60 lots and 28 standard 15 lots were tabulated to show by 5-chain transects the FLS classes and the frequency of each of the recorded classes in the entire lot. These data were punched on cards for the subsequent computer analysis. The calculations furnished all the statistics[4] essential to build sequential graphs for control standards 15 and 60 at 90 and 80 percent confidence levels, and for typical average sample number (A.S.N.) curves and operating characteristic (O.C.) curves (figure 2 for standard 15 at 90 percent confidence level and figure 3 for standard 60 at the 90 percent level). The several graphs (figs. 2-6), and table 2 are related to acceptance-rejection limits of FLS populations (m_1 and m_2) that are representative of the pass and fail criteria for control standards 15 and 60. In all cases (figs. 2-6) equal values were assigned to the probabilities of errors for the pass and fail decisions (i.e., alpha and beta both had the same values of 20 and 10) in preparing the plans at the 80 and 90 percent confidence level.

[4] Equations and mathematical steps needed to devise and check out the computer program for construction of sequential plans are on file at the Pacific Southwest Forest and Range Experiment Station. Also on file are the desk calculator checks of selected problems as well as the computer print-out sheets which show all essential statistics for 52 contract field lots and 9 study plots. For these 61 problems all pertinent statistics for negative binomial (and other distributions) are provided at 90 and 80 percent confidence levels and for at least four different pairs of prescribed acceptance-rejection limits for ribes FLS classes.

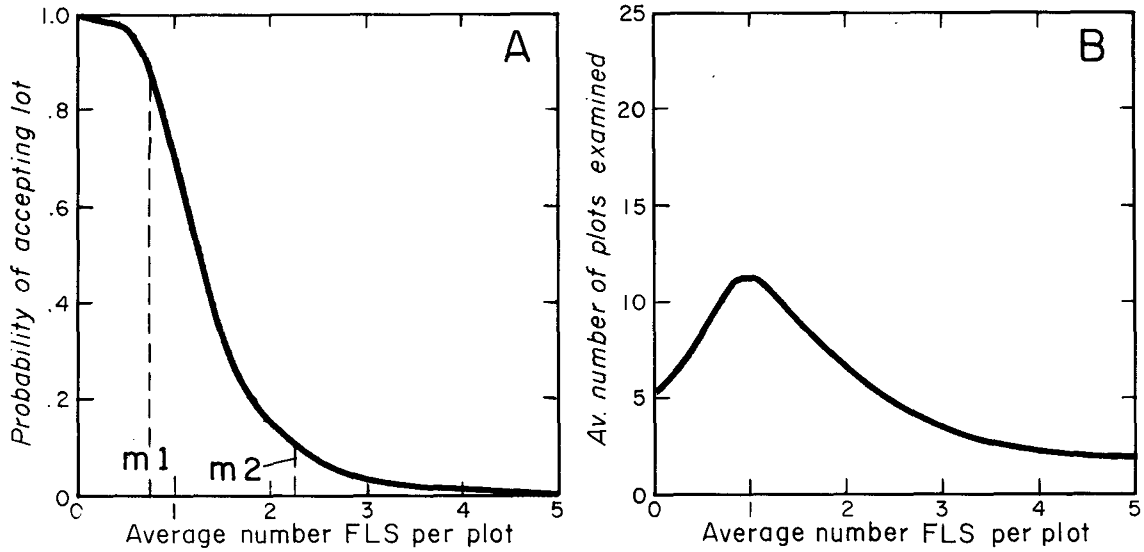


Figure 2.--A, *operating characteristic curve (OC) and* B, *average sample number curve (ASN) for ribes sequential plan. Confidence level of 90 percent and standard 15 level of rust control, acceptance-rejection levels (m_1 and m_2) of 0.75 and 2.25 feet of live stem (FLS).*

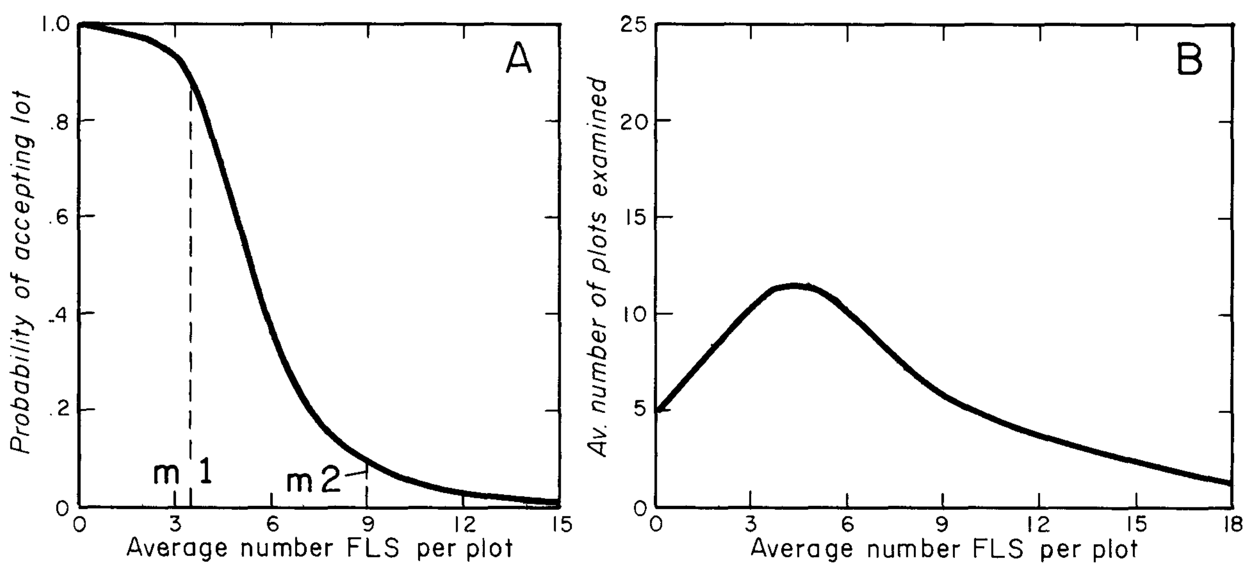


Figure 3.--A, *operating characteristic curve (OC) and* B, *average sample number curve (ASN) for ribes sequential plan. Confidence level of 90 percent and standard 60 level of rust control, acceptance-rejection levels of (m_1 and m_2) of 3.5 and 9.0 feet of live stem (FLS).*

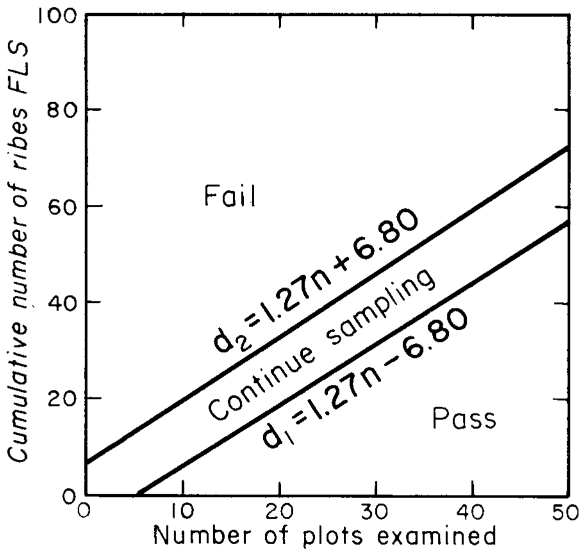


Figure 4.--*Sequential decision lines for standard 15 level of rust control in California. Confidence level of 90 percent, based on Cow Creek No. 2, Stanislaus National Forest data; with range of 0-26 feet of live stem (FLS), mean 2.93 FLS, variance of 19.45 FLS, and acceptance-rejection levels of 0.75 FLS (lower line) and 2.25 FLS (upper line).*

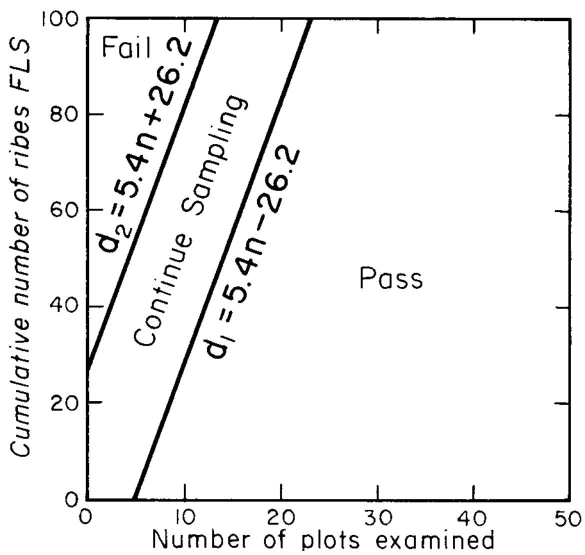


Figure 5.--*Sequential decision lines for standard 60 level of rust control in California. Confidence level of 90 percent, based on Cow Creek No. 2, Stanislaus National Forest data; with range of 0-26 FLS, mean 2.93 FLS, variance 19.45 FLS, and acceptance-rejection levels of 3.5 FLS (lower line) and 9.0 FLS (upper line).*

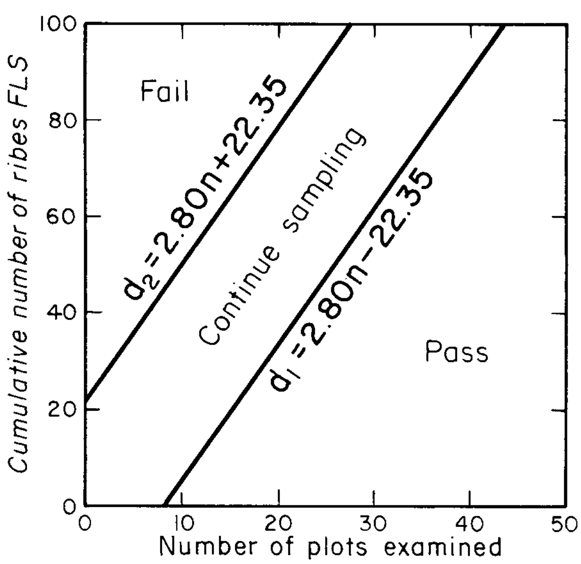


Figure 6.--*Sequential decision lines for standard 60 level of rust control in California. Confidence level of 80 percent, based on Lassen National Forest No. 8 data, with range 0-23 FLS, mean 3.87 FLS, variance 58.11 FLS, and acceptance-rejection levels of 2.0 FLS (lower line) and 4 FLS (upper line).*

Table 2--*Sequential table (equivalent to figure 6) for sampling ribes populations for standard 60 level of rust control in California, 80-percent confidence level*

Number of $\frac{1}{16}$- acre plots examined	Cumulative feet live stem (FLS)[1]	
	Fail[2]	Pass[3]
1	25	--
2	28	--
3	30	--
4	33	--
5	36	--
6	39	--
7	42	--
8	45	1
9	48	3
10	50	6
11	53	9
12	56	12

[1]Rounded to nearest even foot of live stem from decision lines: Fail (d_2) = 2.80n +22.35; Pass (d_1) = 2.80n -22.35.

[2]If cumulative FLS equals or exceeds figure shown in this column, decision is made and no further sampling needed; otherwise, continue sampling.

[3]If cumulative FLS equals or is less than figure shown in this column, decision is made and no further sampling needed; otherwise, continue sampling.

The decision lines for each sequential plan (figs. 4-6) are derived from sample counts of ribes populations on typical tracts of sugar pine forest land and from the equation appropriate to the distribution of the ribes population under study. Sequential plans of this study are based on the negative binomial as given by:

$$d_1 = bn + h_1 \text{ (lower line)}$$
$$d_2 = bn + h_2 \text{ (upper line).}$$

In these equations b provides the slope of the line, n is the appropriate sample number, and h_1 (always a minus value in the negative binomial) and h_2 are the intercepts for the decision lines at slope b.

The computer program for this study has been devised from theories of sequential analysis (Wald 1947) and the negative binomial distribution (Fisher 1941). Applications of these theories to biological problems have been described by Bliss (1953) and others.[5]

[5] See footnote 3.

In the ribes sampling study the essential statistic k used in constructing the graphs (figs. 2-6, and table 2) was derived from iterative calculations based on the ratio of the total number of class units in the sample to the number in the zero class using field records of checking for contract lots that had been worked to standard 15 or 60. This iterative method of calculating k was judged to be the most useful for ribes sampling work after a large number of single-lot and a few pooled-lot examples were tested by other recognized methods for estimating or calculating k (Anscombe 1949; Bliss 1953; Fisher 1953). There is, of course, a danger in the use of a k derived from representative field lots and applying a sequential plan based on this representative k to another field lot. It is believed, however, that the use of such a representative k does not affect the field usefulness of the sequential plan when similar control standards and acceptance-rejection limits are involved. Further field studies should give a measure of the reliability of this assumption.

Reliability and Costs of Sampling

The reliability of and potential savings for sequential sampling of large tracts of forest land were indicated by the three preliminary field trials of sequential and regular sampling checks of ribes populations (by bush count) made in 1956 and 1957. In table 3 results of 13 additional trials made in 1964 on the Shasta and Lassen National Forests compare sequential and regular checks of ribes populations (by live stem count) for relatively small contract lots. In 9 out of these 13 field trials, we reached the same blister rust decision of pass or fail. In all 13 trials, the sequential method took less time than the regular method.

For both sampling methods there is much more variation in data for the mean live stem per acre (1964 tests) than for the mean bushes per acre (1956-1957 tests). Ecologic variance and sample size are largely involved. Within reasonable limits variation in per acre ribes live stem or ribes bush count between sampling methods does not, in itself have practical significance in the control program because quality control decisions usually involve rather large differences in class means. For example, in California we accept lots having 0 to 15 FLS per acre for standard 15 and those having 0 to 60 FLS for standard 60. From a control standpoint an incorrect "pass" decision is a more serious error than an incorrect "fail" call. The latter mistake adds to the control cost but not to the loss of the pine. On this score (table 3) the sequential and regular methods were of comparable accuracy except for two conflicting decisions ("pass" calls that might preferably have been "fail") charged to each method.

In the two lots (PR-250 and IN.B) where sequential check did not give the same control decision as the regular check, there were some factors involved that merit comment. For lot PR-250 there was a congregation of the random plots

Table 3.--*Regular and sequential check of ribes populations, for several blister rust control lots on the Lassen and Shasta National Forests--a comparison of time taken to sample (cost and consistency of the two methods)*

Lot number	Acres in lot	Regular check			Sequential check		
		Time taken to sample	Ribes population	Pass or fail	Time taken to sample	Ribes population	Pass or fail
		Hours	*FLS/acre*		*Hours*	*FLS/acre*	
Lassen N.F.							
PR-270	40	2.15	10.0	Pass	2.10	4.8	Pass
PR-274	42	4.50	63.5	Fail	.40	85.3	Fail
PR-286	80	9.00	11.0	Pass	3.05	6.6	Pass
PR-250	53	2.50	54.0	Fail[1]	2.40	0	Pass[1]
PR-322	80	10.25	14.2	Pass	3.50	85.0	Fail
PR-284	80	9.10	12.0	Pass	3.15	6.7	Pass
PR-326	80	8.55	21.7	Pass	2.25	0	Pass
FSR-263-S	40	4.05	28.0	Pass	2.15	9.6	Pass
FSR-263-N	40	5.10	51.0	Pass	2.25	68.0	Fail
FSR-239	78	7.30	46.2	Pass	4.10	43.0	Pass
FSR-237	36	4.10	36.6	Pass	2.30	10.4	Pass
In. B.	23	3.10	32.8	Fail[1]	3.00	4.0	Pass[1]
Shasta N.F.							
P7	40	4.00	44.0	Fail[1]	2.50	22.5	Fail[1]

[1]Blister rust control standard 15. Other lots were standard 60. All lots worked to appropriate standard.

on a dry brushy slope where few if any ribes occurred. Where there is such a clearly defined difference in ribes habitat the control lot could be stratified and checked on ecologic lines--in this case two sub-blocks of about 30 and 23 acres. With random rather than systematically placed plots, however, some of the advantages of ecologic stratification may be lost when small control blocks are being sampled. Because of the minimum sample-size requirement for a pass decision sequential sampling may not offer much savings in checking small control lots. This factor was of some importance in the case of the 23-acre lot (table 3) marked IN.B. and should be considered before size of block is reduced too much to permit the sampling of more ecologically uniform areas.

Field Use of Sequential Sampling

For the blister rust supervisor and surveyman the essentials of a sequential plan for sampling ribes populations are as follows:

- The appropriate graph (as given by figs. 4-6) or the equivalent numerical guides (table 2 for fig. 6). On the basis of these guides the surveyman accepts or rejects the lot under examination. Either the graph or its corresponding table can be used in the field depending on the preference of the supervisor.
- The operating characteristics curve (OC curve as in figures 2A and 3A) and the average sample number curve (ASN curve as in figures 2B and 3B). Figures 2 and 3 are idealized curves based on actual calculations for a representative field lot of standards 15 and 60. Reservations about the reliability of a representative k as previously made apply also to these OC and ASN curves. The OC curve tells the supervisor in advance of the actual field sampling what to expect on the probability of correctly labeling the lot. The ASN curve shows about how many samples might be needed for a decision of specified accuracy at various prescribed levels of FLS per acre.
- Designation of the desired confidence level, and the acceptance-rejection limits of the ribes populations that are to be appraised.
- An objective and convenient scheme for making random selections of sample plots and an established procedure for determining size, dimensions, and estimated number of sampling units or groups of sampling units that will be needed to provide a reliable checking job.

There are several legitimate ways of randomly selecting small sample plots from the entire area. The following method has been used in some of the field trials. A map of the entire area (control lot) was covered by a transparent grid to divide the entire lot into numbered plots of prescribed sample size and shape. Then from a table of random numbers, or by drawing numbered disks to represent coordinates of measurements, center points of the sample plots were marked on the field map. In ribes survey the sequential sampling has used the same shape and size of plot or transect that has been used for many years for regular checking work. Thus, as mapped in figure 7, the random sequential plots numbered from 1 to 12 (the order drawn) are each 5-chains long by $^{1}/_{4}$-chain wide and are the same shape and size as the 32 line transect plots of the "regular check" (also shown in figure 7). In figure 7 the edge or margin of the lot was not eliminated from the random sampling scheme. Any one of these 5-chain-long plots might have had its origin $^{1}/_{8}$ chain from the edge of the lot.

After the randomly drawn points for the sequential check were spotted on the map the actual plot area to be checked was obtained by joining the starting point of plot 1 to the starting point of plot 2. This line provided the azimuth of plot 1 which extended for 5 chains. Then plot 2 was identified by connecting the beginning of plot 2 with the starting point of plot 3, and so on. Each plot was $^{1}/_{4}$-chain wide. In this way we randomized both plot location and azimuth or plot direction.

When the surveyman goes into the field he should have his map showing the location and compass bearing for the group of plots that will probably be needed to conclude the check. Single plots should be checked in the random order as drawn. Other random methods of locating continuous strips across contours (more closely simulating the regular checking use of continuous strip transects) may be used instead of the scheme illustrated in figure 7. If the area under examination is difficult to walk over (i.e., steep or brushy) and it is considered uneconomic to check single plots in the order

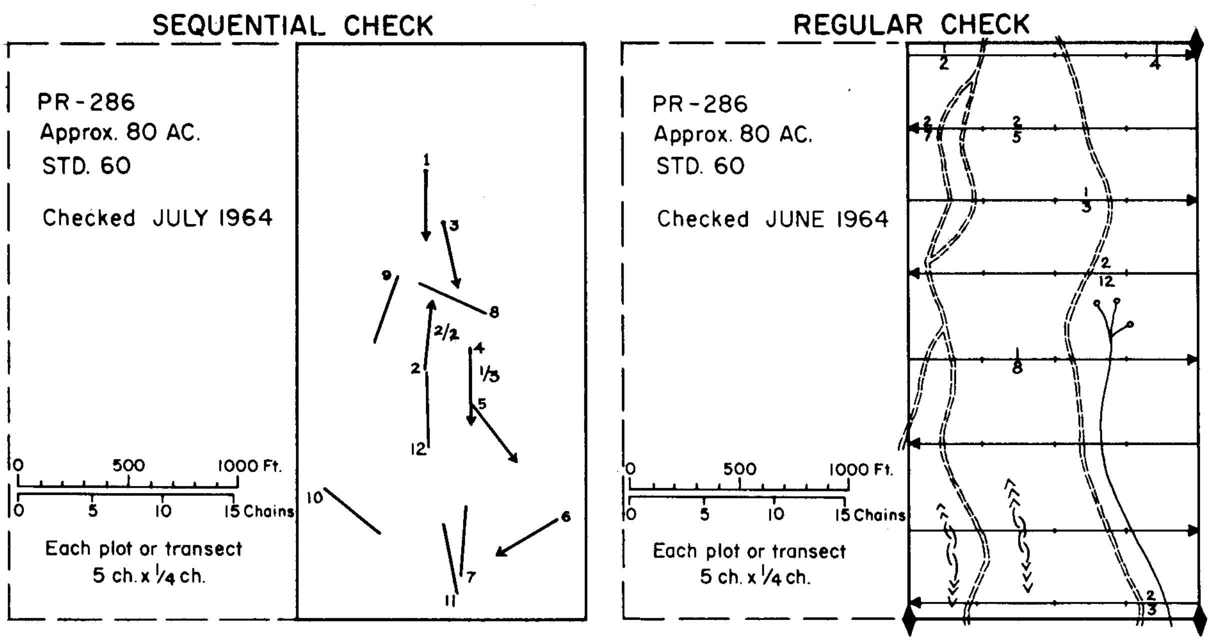


Figure 7.--*Ribes bush and live stem data for sequential and regular checks on the same 80-acre lot, SW 1/4 of section 13, T.26N, R.6E. Note location of 12 randomly drawn plots of the sequential check; this check was terminated at plot 6 because a decision had been reached; plot 2 showed two ribes with 2 feet of live stem and plot 4 showed one ribes with 3 feet of live stem.*

drawn, the use of a "group convenience" plan may be justified. On a 40-acre lot, for example, field experience shows that a sequential decision may be reached when about eight plots have been checked. In the group convenience scheme, therefore, eight plots would be chosen at random and located on a map of the control lot. Then the starting point, or first plot to be checked, would be determined by chance and the remaining plots joined in a closed traverse to minimize walking. Decision to accept or reject is then made in the usual manner.

From the control objectives as noted in table 4 the most appropriate sequential plan is selected from prior knowledge of the ribes population and rust hazard in the block to be sampled. If prior information about ribes population is not available, an estimate of the variance may be made from a small group of plots to be checked by the group convenience scheme. Such a procedure would be helpful in maintaining control over the size of sample.

To date sequential ribes surveys have not been tested extensively enough in the field to prescribe with confidence the most efficient sample number, shape, and size of sampling plot for work blocks of various sizes. Until more experience is gained table 4 may serve as a guide for choosing a suitable sequential plan for additional field trials of control lots for several combinations of rust standards at 90 and 80 percent confidence levels. For many checking objectives, and at the estimated reliability of present regular survey methods, sequential procedures probably should be used at the 80 percent confidence level (fig. 6 or table 2). When the blister rust hazard is high (standard 15) and when a high level of confidence is desired, the sequential plan provided by figure 4 is suggested; for standard 60, at less exacting acceptance-rejection levels figure 5 may be most useful. The plan of figure 6 or table 2 may be the most widely applicable one for control units of about 40 acres for a medium or low hazard situation at standard 60 level. This combination of lot size and control standard is one commonly encountered in field operations.

In the sequential checking procedure there is

Table 4.--*Guide to selection of sequential plan most appropriate to the desired blister rust control objective in sugar pine forest areas of California*

Blister rust hazard	Blister rust control standard[1]	Acceptance-rejection levels prescribe [1]	Confidence level	Graph in this report
	Feet live stem	*Feet live stem*	*Percent*	
High	15	0.75-2.25	90	Fig. 4
Low	60	3.50-9.00	90	Fig. 5
Medium	60	2.00-4.00	80	Fig. 6[2]

[1]Standards and acceptance-rejection levels as recommended for field use in California refer to average allowable linear feet of ribes live stem per acre or per cumulative sampling unit. Survey records show a consistent trend of ratio between live stem and bush counts on sample plots. Thus live stem class means of 0.75-2.25, 2.00-4.00 or 3.50-9.00 might be used as bush counts for certain survey objectives.

[2]See table 2 for a numerical equivalent.

the opportunity, as in the regular checking, of observing off-plot ribes in following the compass traverse between random sampling units. In some cases sequential check may involve more walking than the regular check, though usually it does not. Information on "off-strip" ribes is valuable in deciding when to truncate sequential measurements if no clear-cut decision has been reached. Much work has been done and more is being done by Forest Service statisticians on reliability of truncating sampling measurements. We know that sequential sampling can, in theory, continue without a definite decision until most or all of the lot has been sampled. But in practice, guide lines should be set whereby administrative judgment and unbiased sampling are used at optimum levels to achieve control objectives. In control units where rust hazard is high the best checking procedure might consist of a rapid sequential check of the unit as a whole with supplemental checking directed to stream type or a moist meadow, where rust-spreading ribes are apt to occur.

In conclusion the attention of field supervisors is directed to the idea of using an appropriate sequential plan to aid decision making on the need for control work. This is a substitute for an informal administrative examination where a formal quality control check is not specified. In using a sequential guide for this administrative check there is no need to tie into control lot boundaries or to run accurate transect lines provided all random sample plots are comparable in size and shape and are known to be within the area under examination.

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GPO 974-495