

A Field Guide for Surveying Soil Disturbance Using Random Sampling

Prepared by Bill Chapman, PhD¹; Steve Thompson, BSc²; Peter Ott, MSc¹; Mike Curran, PhD¹; Shannon Berch, PhD³

Introduction

This field guide outlines a random sampling procedure for estimating levels of dispersed soil disturbance in Standards Units (SUs) of all sizes. This method can be used to assess the effectiveness of soil conservation practices under the Forest and Range Evaluation Program (FREP), or for Compliance and Enforcement Investigations and other circumstances where measures of soil disturbance are needed. This sampling procedure is intended for use with the following companion documents.

- FREP Soil Conservation Field Cards
- *OziExplorer Training and Help Manual*
- *Protocol for Soil Resource Stewardship Monitoring: Cutblock Level*

These documents are located under the “Soils” resource value at: <http://www.for.gov.bc.ca/hfp/frep/indicators/table.htm>

The sampling procedures described in this technical note are applicable to dispersed disturbance in the Net Area to be Reforested (NAR) and in Roadside Work Areas (RWA). The terms “SU,” “NAR,” and “RWA” all have legal definitions in British Columbia forestry. It is assumed the reader is familiar with current legislation and the description of counted soil disturbance (B.C. Ministry of Forests 2001). Soil disturbance that results from “Temporary Access Structures” may be counted as a category of disturbance within a random dispersed disturbance survey, or it may be surveyed separately using any of the standard methods for measuring road area, which are available from many other sources.

Although transect-based survey methods exist (e.g., B.C. Ministry of Forests 2001), a random sample gives the best estimate of disturbance for a given sample size and it is straightforward to calculate a statistical test to verify results. The random method also requires very little layout time and is easily scaled to different-sized areas and complex shapes. Some of the advantages of random sampling are discussed in Bergerud (2004).

¹ B.C. Ministry of Forests, Lands and Natural Resource Operations
² Frontline Forest Research, Nelson, B.C.
³ B.C. Ministry of Environment, Environmental Sustainability and Strategic Policy Division

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Many different configurations of hardware and software can be used to locate points for a random survey. The survey procedure outlined here uses commonly available technology. Regardless of the equipment used, a random survey must meet the following criteria to be acceptable.

1. The observation points must be randomly generated with any point in the survey area having a chance of being sampled.
2. When the observation point is located in the field, the exact survey point must be selected by following a precise rule that eliminates the opportunity for surveyor bias to influence selection.
3. All points generated for a particular survey area must be evaluated. It is expected that random survey points and soil disturbance will be distributed unevenly throughout the survey area. Therefore, the entire set of points must be surveyed and evaluated before making judgements about the overall level of disturbance. Initially, a complete survey with a smaller number of points is possible. If this survey is subsequently found to have insufficient power to give a clear result, an additional set of random points can be generated for the same area and surveyed. These results can then be combined with the previous survey to generate a more precise estimate.

The goal of effectiveness evaluations is to determine whether practices are effective at achieving objectives, whereas a compliance-type survey assesses whether the level of prescribed disturbance has been exceeded.

The estimate of disturbance from a sample is subject to sampling error, and therefore a one-sided *t*-test is used to give a measure of the power of the sampling procedure. For investigations into excess soil disturbance resulting from forestry operations in British Columbia, a statistically significant, one-sided *t*-test at the 90% confidence level is typically considered as a sufficient indicator that the soil disturbance limit has been exceeded.

Survey Procedure

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1. **Preliminary Assessment and Mapping** – The recommended procedure is to **review** high-resolution digital imagery (i.e., 10 cm per pixel, or less) to **assess** the amount and distribution of disturbance, **delineate** the RWA and temporary access structures, and **identify** areas with potential environmental damage. For detailed instructions, see the *OziExplorer Training and Help Manual* (<http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/indicators/OziExplorer-Training-and-Help-Manual-May-2009.pdf>).

Delineate (stratify) areas with different concentrations of disturbance on the aerial photo. Stratification can improve the efficiency of a random survey and is recommended for large SUs with highly clustered disturbance (see “Guidelines for Stratification” below).

As an alternative to aerial photo assessment, conduct a field reconnaissance of the survey area to assess the distribution and severity of soil disturbance. The RWA can be defined from a ground survey, but this is very time consuming.

The survey area can include one or all SUs in a cutblock. The RWA is always treated as a separate SU and, depending on the level of disturbance, may or may not be surveyed. If a cutblock contains multiple SUs, it will not be necessary to survey all of them, as the unit of assessment (effectiveness or compliance) is the SU or the RWA.

If “Damage to the Environment” under the *Forest and Range Practices Act* is suspected, then a survey may also be undertaken on smaller areas within an SU. If a survey is

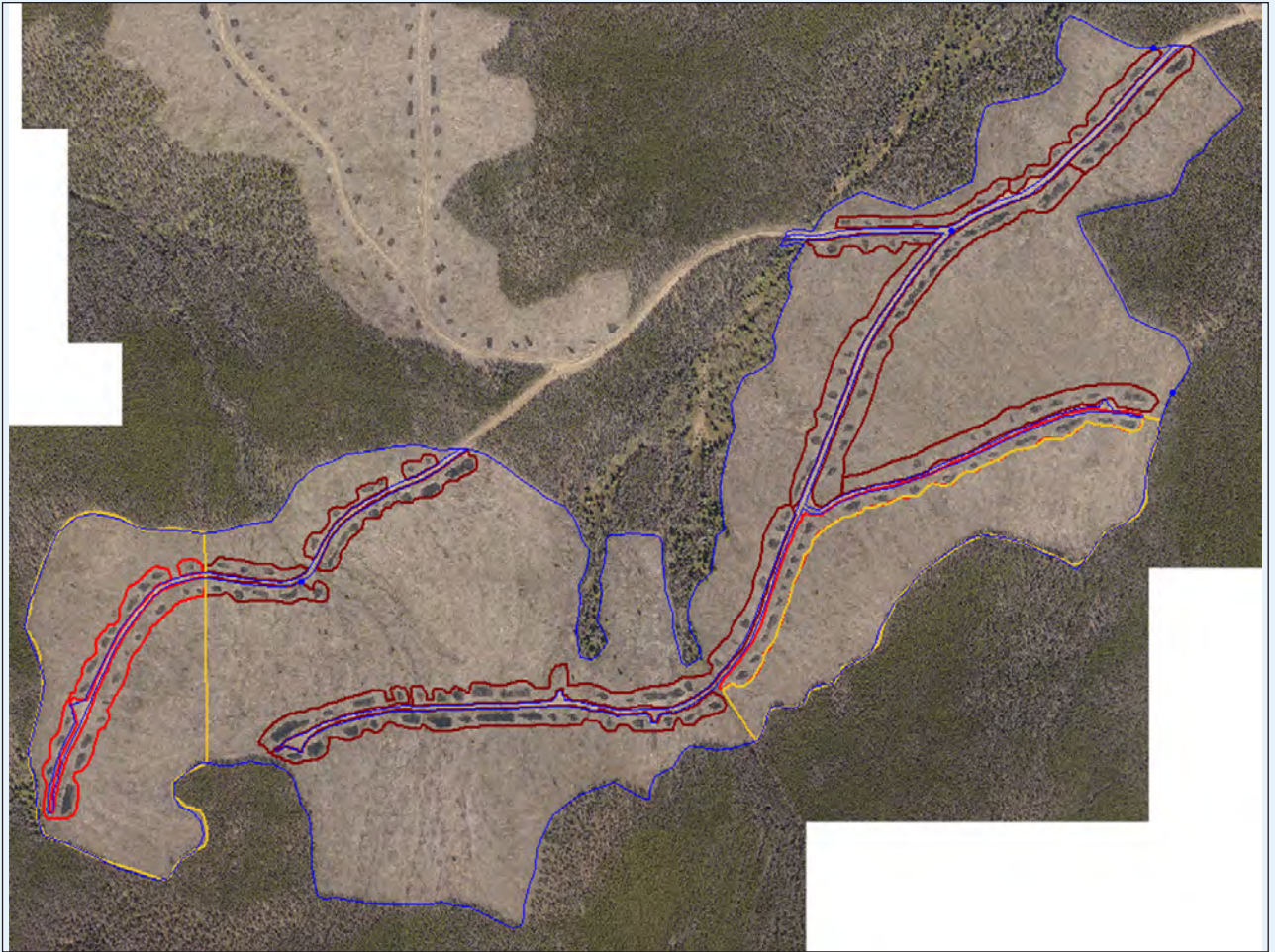


Figure 1: Example of stratification from a high-resolution aerial photo. In this case, the SU was divided into two strata (blue and yellow boundaries). The yellow stratum is not contiguous. The red lines show the location of RWAs mapped from the photo. In this example, the RWA has also been divided into two strata, corresponding to the different shades of red (which sometimes appears pinkish where it is adjacent to a blue line). The strata were selected because of visibly differing levels of soil disturbance, although the differences are not discernible at the scale shown. This image (~10 cm per pixel) can be greatly magnified without pixilation.

used to gather evidence for a “Damage to the Environment” action, then the area to be surveyed is defined by the expert giving evidence on the likelihood of environmental damage.

Map the survey area boundaries using the SU boundaries defined in the site plan, except for RWA boundaries, which are best determined from aerial photos.

- Exclude roads, landings, or other features that are not part of the NAR.
- Identify and map temporary access structures, such as roads and turnouts (if these are to be measured separately).

Figure 1 shows an example of boundaries mapped from a high-resolution aerial photo.

Create a digital map of the survey area using suitable GIS software (e.g., *OziExplorer*, *ArcMap™*, or *Global Mapper™*). Note the map datum so that a GPS can be set to match the map.

2. **Determine Sample Size** – *Review* survey objectives and *determine* sample size. The number of points to be sampled is determined by the expected level of disturbance and the desired confidence interval. With higher disturbance levels, fewer points are needed in the field survey to establish that the cutblock is over the prescribed disturbance limit.

For a typical compliance and enforcement survey of dispersed disturbance, 200 sample points are recommended in an SU with 5–15% disturbance. This gives a critical value that is approximately 3% less than the estimated mean using a one-sided t-test at the 90% Confidence Level (Table 1).

Typically, SUs will be considered in non-compliance if the measured disturbance exceeds 13% for a 10% disturbance limit block, or 8% for a 5% limit block.

For effectiveness evaluations, in which samples usually consist of many cutblocks, a 100-point survey is considered a good trade-off between sampling power and use of resources. For surveys

Table 1: Critical value for a one-sided t-test at the 90% confidence level

| Percent Disturbance | Number of Survey Points | | | | | | | | | | | |
|---------------------|-------------------------|------|------|------|------|------|------|------|------|------|------|------|
| | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 150 | 200 | 250 |
| 5 | | | | | | | 7.8 | 7.7 | 7.6 | 7.3 | 7.0 | 6.8 |
| 6 | | | | | | 9.3 | 9.1 | 8.9 | 8.8 | 8.5 | 8.2 | 7.9 |
| 7 | | | | | 10.7 | 10.5 | 10.3 | 10.2 | 10.0 | 9.7 | 9.3 | 9.1 |
| 8 | | | | 12.2 | 11.9 | 11.7 | 11.5 | 11.4 | 11.2 | 10.9 | 10.5 | 10.2 |
| 9 | | | 13.8 | 13.5 | 13.2 | 12.9 | 12.7 | 12.5 | 12.4 | 12.0 | 11.6 | 11.3 |
| 10 | | 15.6 | 15.1 | 14.7 | 14.4 | 14.1 | 13.9 | 13.7 | 13.5 | 13.2 | 12.7 | 12.4 |
| 11 | | 16.8 | 16.3 | 15.9 | 15.5 | 15.3 | 15.1 | 14.9 | 14.7 | 14.3 | 13.9 | 13.5 |
| 12 | | 18.0 | 17.5 | 17.1 | 16.7 | 16.4 | 16.2 | 16.0 | 15.8 | 15.4 | 15.0 | 14.6 |
| 13 | 20.0 | 19.2 | 18.7 | 18.2 | 17.9 | 17.6 | 17.4 | 17.2 | 17.0 | 16.5 | 16.1 | 15.7 |
| 14 | 21.2 | 20.4 | 19.9 | 19.4 | 19.0 | 18.7 | 18.5 | 18.3 | 18.1 | 17.7 | 17.2 | 16.8 |
| 15 | 22.5 | 21.6 | 21.0 | 20.6 | 20.2 | 19.9 | 19.6 | 19.4 | 19.2 | 18.8 | 18.3 | 17.9 |
| 16 | 23.7 | 22.8 | 22.2 | 21.7 | 21.3 | 21.0 | 20.8 | 20.5 | 20.3 | 19.9 | 19.3 | 19.0 |
| 17 | 24.8 | 24.0 | 23.3 | 22.9 | 22.5 | 22.1 | 21.9 | 21.6 | 21.4 | 21.0 | 20.4 | 20.1 |
| 18 | 26.0 | 25.1 | 24.5 | 24.0 | 23.6 | 23.3 | 23.0 | 22.7 | 22.5 | 22.1 | 21.5 | 21.1 |
| 19 | 27.2 | 26.3 | 25.6 | 25.1 | 24.7 | 24.4 | 24.1 | 23.8 | 23.6 | 23.1 | 22.6 | 22.2 |
| 20 | 28.3 | 27.4 | 26.7 | 26.2 | 25.8 | 25.5 | 25.2 | 24.9 | 24.7 | 24.2 | 23.6 | 23.3 |
| 21 | 29.5 | 28.6 | 27.9 | 27.3 | 26.9 | 26.6 | 26.3 | 26.0 | 25.8 | 25.3 | 24.7 | 24.3 |
| 22 | 30.6 | 29.7 | 29.0 | 28.5 | 28.0 | 27.7 | 27.4 | 27.1 | 26.9 | 26.4 | 25.8 | 25.4 |
| 23 | 31.8 | 30.8 | 30.1 | 29.6 | 29.1 | 28.8 | 28.5 | 28.2 | 28.0 | 27.4 | 26.8 | 26.4 |
| 24 | 32.9 | 31.9 | 31.2 | 30.7 | 30.2 | 29.8 | 29.5 | 29.3 | 29.0 | 28.5 | 27.9 | 27.5 |
| 25 | 34.0 | 33.0 | 32.3 | 31.7 | 31.3 | 30.9 | 30.6 | 30.3 | 30.1 | 29.6 | 28.9 | 28.5 |
| 26 | 35.2 | 34.1 | 33.4 | 32.8 | 32.4 | 32.0 | 31.7 | 31.4 | 31.2 | 30.6 | 30.0 | 29.6 |
| 27 | 36.3 | 35.2 | 34.5 | 33.9 | 33.5 | 33.1 | 32.8 | 32.5 | 32.2 | 31.7 | 31.0 | 30.6 |
| 28 | 37.4 | 36.3 | 35.6 | 35.0 | 34.5 | 34.1 | 33.8 | 33.5 | 33.3 | 32.7 | 32.1 | 31.7 |
| 29 | 38.5 | 37.4 | 36.7 | 36.1 | 35.6 | 35.2 | 34.9 | 34.6 | 34.4 | 33.8 | 33.1 | 32.7 |
| 30 | 39.6 | 38.5 | 37.7 | 37.1 | 36.7 | 36.3 | 35.9 | 35.7 | 35.4 | 34.8 | 34.2 | 33.7 |
| 35 | 45.0 | 43.9 | 43.0 | 42.4 | 41.9 | 41.5 | 41.2 | 40.9 | 40.6 | 40.0 | 39.3 | 38.9 |
| 40 | 50.2 | 49.1 | 48.3 | 47.6 | 47.1 | 46.7 | 46.4 | 46.1 | 45.8 | 45.2 | 44.5 | 44.0 |
| 45 | 55.4 | 54.2 | 53.4 | 52.7 | 52.2 | 51.8 | 51.5 | 51.1 | 50.9 | 50.2 | 49.5 | 49.1 |
| 50 | 60.4 | 59.3 | 58.4 | 57.8 | 57.3 | 56.8 | 56.5 | 56.2 | 55.9 | 55.3 | 54.6 | 54.1 |
| 55 | 65.4 | 64.2 | 63.4 | 62.7 | 62.2 | 61.8 | 61.5 | 61.1 | 60.9 | 60.2 | 59.5 | 59.1 |
| 60 | 70.2 | 69.1 | 68.3 | 67.6 | 67.1 | 66.7 | 66.4 | 66.1 | 65.8 | 65.2 | 64.5 | 64.0 |
| 65 | 75.0 | 73.9 | 73.0 | 72.4 | 71.9 | 71.5 | 71.2 | 70.9 | 70.6 | 70.0 | 69.3 | 68.9 |
| 70 | 79.6 | 78.5 | 77.7 | 77.1 | 76.7 | 76.3 | 75.9 | 75.7 | 75.4 | 74.8 | 74.2 | 73.7 |
| 75 | 84.0 | 83.0 | 82.3 | 81.7 | 81.3 | 80.9 | 80.6 | 80.3 | 80.1 | 79.6 | 78.9 | 78.5 |
| 80 | 88.3 | 87.4 | 86.7 | 86.2 | 85.8 | 85.5 | 85.2 | 84.9 | 84.7 | 84.2 | 83.6 | 83.3 |

* Blank values are shown where use of this table is not recommended

associated with effectiveness evaluations, however, a cutblock is considered over the limit if the mean is over the limit, as the true disturbance in the block is likely closer to the mean than the confidence limit.

Because of mapping or GPS errors, some points will inevitably fall on permanent landings, roads, or other non-surveyed areas (e.g., a large pile of slash). Therefore, it is often more efficient to generate 10% more points (e.g., 110 points for a 100-point survey); then, if some points are dropped during the survey, an adequate sample can still be obtained without having to generate another set of survey points.

- 3. Generate Random Waypoints and Download to GPS** – This step can be done with suitable GIS software and with the digital map generated during Step 1 (above).

For example, a point shapefile can be generated in ArcMap, using a Visual Basic for Applications macro developed by Sawada.⁴ The shapefile is then converted to waypoints in *OziExplorer* (or other mapping software that has this function). The waypoints are then downloaded to a suitable GPS unit. Production of a paper or digital map is recommended to assist in tracking field survey progress.

Field

- 4. Determine the Hazard Rating for the SU** – Under the *Forest and Range Practices Act*, the Crown does not verify any soil hazard ratings⁵ that may be given in the site plan; therefore, soil hazard ratings must be independently determined by the surveyor. This hazard rating is then used to determine which soil disturbance categories count and the disturbance limits for the area to be surveyed. This may be done either before or after the survey is completed, as long as all disturbance types are described at each survey point.
- 5. Verify that the GPS and Map Correspond** – If the GPS and map are in different map datums, or if the map has been georeferenced incorrectly, then a significant shift between the GPS readings and the map is possible, causing some survey points to be located outside of the sampled SU. Map correspondence can be checked by determining the GPS location of three or more points that are clearly and precisely located on the aerial photograph.
- 6. Traverse Recording** – Before surveying, switch on the tracking function in the GPS so the traverse route will be recorded.
- 7. Locate Survey Points in the Field** – For field location of survey points, the recommended procedure is to use built-in GPS features to navigate from waypoint to waypoint. Wherever feasible, approach the next waypoint from the general direction of the previous waypoint. In the final 10 m before a point, the surveyor should focus on the GPS unit and walk in a straight line at an even pace. If adjacent points are less than 10 m apart, ensure the approach to each point begins at least 10 m away. Do not use a haul road as the starting point when locating points in an RWA survey.
8. Navigation to a point is complete when the GPS indicates it is 1 m from the waypoint. This is determined by observing the changing distance to the waypoint on the GPS, or by programming the GPS to beep at a 1 m distance from the point. At precisely the moment when the 1 m distance is indicated, the exact survey point is identified by an arbitrary locator that is determined in advance and is consistently used throughout the survey.

⁴ Sawada, M. Random point generator, a VBA macro available from ESRI ArcScripts at: <http://arcscripts.esri.com/details.asp?dbid=12098> (Accessed March 2013).

⁵ Soil hazard ratings, which are a necessary prerequisite to conducting a soil disturbance survey, are described in the *Hazard Assessment Keys for Evaluating Site Sensitivity to Soil Degrading Processes Guidebook* (B.C. Ministry of Forests 1999).

Examples of locators are the point directly below one corner of the GPS unit, or the end of a heavy or weighted piece of flagging that hangs from the strap of the GPS. The surveyor marks the point immediately and must not adjust its location in any way. Because of the GPS's built-in variability, the reading may change while the surveyor is standing there; however, this will not matter as the surveyor uses the initial indication of the point.

The surveyor navigates to a location 1 m from the point because it is simply too time consuming to locate the point with any more precision (and most GPS units would not be able to do this anyway). If relocation of a point is attempted with the GPS, it is unlikely that the exact point would be found, but this is not important as the original point will have been located in an unbiased manner.

9. Field Marking and Data Recording –

For compliance surveys, the exact survey point should be semi-permanently marked. This is not necessary for effectiveness evaluation surveys unless they are subject to audit. Survey results can be entered directly into a GPS unit or an electronic data entry device, or recorded on notepaper.

10. Calculations –

When the survey is complete, compare the estimated mean to the prescribed soil disturbance limit using a one-sided *t*-test at the 90% confidence level. The formulae to calculate the critical value for this test are shown below.

If the critical value is greater than the prescribed soil disturbance limit, then the survey area is typically considered to be over the disturbance limit.

$$p = \frac{\text{counted disturbance points}}{n}$$

$$\text{Mean} = 100 \times p$$

$$\text{Variance} = \frac{p \times (1 - p)}{(n - 1)}$$

$$\text{Critical Test Value} = \text{Mean} - 100 \times t_{(0.1, n-1)} \times \sqrt{\text{Variance}}$$

Where: *n* = total number of survey points; and $t_{(0.1, n-1)}$ = Student's *t* statistic for a one-sided test at the 90% confidence level.

Note: If you are using Excel to calculate the *t* value, the function "TINV" assumes a two-tailed probability. To specify the correct value for TINV in a one-sided test, set $\alpha = 0.2$ (i.e., $\text{TINV}_{[0.2, n-1]}$).

Calculations for Multiple Strata (Stratified Random Sample)

If there is more than one stratum in the survey area, calculate the overall mean disturbance using a weighted mean and the lower confidence limit using a weighted standard error (SE). Weighted standard error is calculated stepwise by calculating the variance in each stratum, using the formula above and then combining the numbers on an area weighted basis:

$$\text{Weighted SE} = \sqrt{\sum_{i=1}^S \left(\frac{\text{Area}_i^2}{\text{Area}_{\text{Total}}^2} \times \text{Variance}_i \right)}$$

Where: Area_i = area of stratum "i"; $\text{Area}_{\text{total}}$ = total area of all strata; *S* = number of strata; and

Variance_i = variance of *Stratum_i*, calculated as above.

An example calculation of the weighted mean and SE in a 100-ha SU with two unequal-sized strata of 25 and 75 ha is shown below. A total of 114 points were surveyed in the smaller stratum, with 23 counted disturbance points (20.2%). Eighty-six points were surveyed in the larger stratum with 4 counted disturbance points (4.7%).

$$\begin{aligned} \text{Weighted Mean} &= \left(\frac{25 \text{ ha}}{100 \text{ ha}} \times 20.2\% \right) + \left(\frac{75 \text{ ha}}{100 \text{ ha}} \times 4.7\% \right) \\ &= 5.05\% + 3.53\% = 8.58\% \end{aligned}$$

$$\text{Variance}_1 = 100 \times \left[\frac{\frac{23}{114} \times \left(1 - \frac{23}{114}\right)}{(114 - 1)} \right] = 0.1425$$

$$\text{Variance}_2 = 100 \times \left[\frac{\frac{4}{86} \times \left(1 - \frac{4}{86}\right)}{(86 - 1)} \right] = 0.0522$$

$$\text{Weighted SE} = \sqrt{\left[\frac{25^2}{100^2} \times 0.1425 + \frac{75^2}{100^2} \times 0.0522 \right]} = 2.73\%$$

Guidelines for Stratification

Stratification may improve the efficiency of a survey, particularly if an aerial photo or other type of preliminary review shows large variability in the distribution of disturbance within an SU. In such cases, every portion of a surveyed area may not require sampling at the same intensity. The potential benefits of stratification are greatest with very large SUs.

Strata must be mutually exclusive, collectively account for the total area of the SU, and delineated before the field survey begins. This is most efficiently done using a high-resolution aerial photo (i.e., 10 cm per pixel or less). Figure 1 shows an example of stratification from an aerial photo review.

If more than one stratum is assessed in the survey area, final results are calculated with area-weighted means and variances. Using weighted means and variances compensates for the unequal allocation of survey points to strata so that a stratified random sample still gives a valid estimate of the overall disturbance level for the entire area surveyed.

Individual strata can consist of dispersed areas; for example, a number of mappable, non-contiguous, small-sized wetter areas within a larger survey area can be surveyed as one stratum.

For very large SUs, stratification may also be used to implement a multi-step effectiveness or compliance survey. This is done by identifying a stratum (via a preliminary assessment) within the SU that has above-average disturbance. Following the stratum sample size guidelines below, a survey is done on this smaller area. The results are then used to determine whether additional surveying is warranted in the other strata. For example, if the survey results clearly show the most disturbed stratum is low or in compliance, then it may not be worth surveying the remaining strata, which are presumed to have less disturbance. To improve interpretation, it may be desirable to include extra sample points in this first step.

This procedure can only be used if a surveyor can provide convincing evidence that a more disturbed area has been stratified out. High-resolution photography is useful to support such a position.

Calculating Stratum Sample Size

Sample size is a function of the number of points in the total survey area, the estimated disturbance, and the area of the stratum.

Estimate the amount of disturbance in each stratum (via preliminary assessment), and then calculate the sample size by weighting the number of points for each stratum using the formula below. In all cases, a minimum of 15% of the total sample should be used in each stratum (e.g., 30 points in a 200-point total sample). The surveyor can increase the number of points in a stratum of interest as this will not affect the final weighted average calculation of disturbance.

$$n_i = \frac{Area_i \times \sqrt{p_i(1-p_i)}}{\sum_{i=1}^S Area_i \times \sqrt{p_i(1-p_i)}} \times n_{Total}$$

Where: $Area_i$ = area of stratum "i"; S = number of strata; and p_i = estimated proportion of disturbed points.

Consider the example of a 100 ha survey area with two strata. One stratum is 25 ha with disturbance estimated at 20%. A second stratum is 75 ha with disturbance estimated at 5%. For a 200-point survey, sample sizes in each stratum would be estimated as:

$$n_{25} = \frac{25 \times \sqrt{0.20(1-0.20)}}{25 \times \sqrt{0.20 \times (1-0.20)} + 75 \times \sqrt{0.05(1-0.05)}} \times 200 = \frac{25 \times 0.4}{25 \times 0.4 + 75 \times 0.218} \times 200 = 76$$
$$n_{75} = \frac{75 \times \sqrt{0.05 \times (1-0.05)}}{25 \times \sqrt{0.20 \times (1-0.20)} + 75 \times \sqrt{0.05 \times (1-0.05)}} \times 200 = \frac{75 \times 0.218}{25 \times 0.4 + 75 \times 0.218} \times 200 = 124$$

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For further information contact:

Bill Chapman
B.C. Ministry of Forests, Lands and Natural Resource Operations
200-640 Borland Street
Williams Lake, BC, V2G 4T1
250-398-4718
Bill.Chapman@gov.bc.ca



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