Revised February 2017

Case Studies in Forest Management

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Table of Contents

Definition & Purpose 3

Objectives 3

Prospective and Retrospective Case Studies 3

Case-study Design 4

Importance of Standard Methods 5

Submitting Data 7

Submitting a Completed Case-study 7

Procedure for Measuring Regeneration/BA 8

Analysis and Use of Regeneration/BA Plot Data 14

Procedure for Monitoring Growth 19

Analysis and Use of Stand-growth (BA) Data 20

Field Procedure for Monitoring Radial Growth of Residual Trees 22

Analysis and Use of Radial-growth Data 255

Procedure for Monitoring Plant Diversity 29

Analysis and Use of Species-area Plot Data 32

Definition & Purpose

Case studies monitor the effect of silvicultural treatment(s) on tree regeneration, tree growth, and understory richness of forested Native Plant Communities. Standard measurements are taken at points that can be re-located within GPS accuracy and re-measured. Case studies are to be documented and published on a standard template for the purpose of sharing forest-management experiences at the stand scale over time.

Objectives

The **primary objective** of a case study is to monitor the success or failure of a treatment's stated purpose. Nearly all silvicultural practices are performed to either regenerate a cohort of trees or to improve the growth of residual trees. Thus silvicultural "success" will be measured primarily by regeneration and growth.

The **secondary objective** of a case study is to monitor the impact of the treatment on the forest ecosystem. We have chosen to measure plant diversity and understory composition as a means of inferring the conservation or loss of ecological function.

Prospective and Retrospective Case Studies

There are two kinds of case studies, prospective and retrospective. A prospective study looks forward, measuring the effectiveness of a planned silvicultural treatment to change a forest from its current condition to a desired future condition. The comparison to be made is between before and after measurements of tree composition, tree density, regeneration, recruitment, or the effect on groundlayer diversity. Sample points or plots are to be marked with wire pin-flags and GPS coordinates recorded so that re-sampling can occur at least within GPS accuracy if not at the exact same points. Normally stands are re-sampled after 5 full growing seasons, but the data are archived and re-measurement of older case studies can occur at any time. Thus, for prospective studies the comparisons are temporal … something is measured, a treatment applied, and something is re-measured using the exact same plots and methods and the difference is attributed to the treatment.

A retrospective study looks backward, in an attempt to understand how past management of a forest stand caused its current condition. Such studies can be applied to a forest of any age as long as there are reasonably good records of silvicultural treatment. In some cases, the old records may include regeneration checks or an inventory of trees that can be re-measured in ways that match the original assessment. In many cases there will be no pre-treatment or follow-up data. When that happens, a retrospective case-study must include either a control plot in an untreated, adjacent stand or must rely on "benchmarks" for comparing tree composition, tree density, regeneration, recruitment, or the effect on the groundlayer. Benchmarks provide averages based upon unmanaged stands that are the same Native Plant Community and roughly the same age as the study site. Samples taken require GPS coordinates to allow for re-measurement, but in most cases there will be no further measurement and thus need to leave pin-flags or other markings. Thus, in contrast to prospective studies, the comparisons in a retrospective study are usually spatial between a treated site and one untreated site by way of a control or by way of benchmarks.

Case-study Design

In prospective case studies of regeneration or effect on the groundlayer, individual treatments are tracked separately in the DNR case-study database. A prospective case study can comprise one to several treatments depending upon the purpose. For example, a strip thinning or group selection harvest of a forest stand results in two treatments: harvested areas and leave patches. If the purpose is to just document what happens in the harvested areas, there is a single treatment. If the purpose is to compare harvested areas to the leave patches, then there are two treatments to document and compare in a single case-study write up.

Retrospective case studies of regeneration or effect on the groundlayer are harder to design because the uniformity of treatment is often unknown. In plantations and even-aged forests uniformity is assumed, but one must find an untreated control nearby or rely upon benchmarks for some comparisons. For intermediate treatments, uniformity is not assumed. Archived documents or historic air photos are the best source for determining uniformity. If the treatment was patchy then the patches must be reconstructed and sampled as independent treatments.

Retrospective studies of growth are different because we want to understand the response of trees to release or damage, by species. Tree species are placed into treatments that reflect the combinations of release or damage in the stand. The tree species of interest, the release categories, and damage categories are entirely the choice of the forester. For example, mixed stands of northern hardwoods are often thinned to improve the growth of red oak. If all red oaks were released on the same two sides and the forester was interested only in undamaged red oaks, then the study would consist of a single tree category. If the forester was interested in comparing red oaks to basswoods, two-sided release to full release, and damaged trees versus undamaged ones, the study would consist of 6 categories.

For all case studies, quantitative comparison is at the heart of the design. It is important to think through what comparisons are of interest and make sure that all sample plots are placed in the right locations or that the right trees have been selected for coring. Reading through the *Analysis and Use* sections of this document can be helpful in understanding design.

Importance of Standard Methods

Standard monitoring methods are necessary in before-and-after sampling so that differences can be calculated for discussion. Also, it is very important to have standards so that case studies can be compared or grouped for a large synthesis. For example, we might want to combine several case studies with similar treatments by Native Plant Community (NPC) so that we can calculate a rate of success and make comparisons among different NPCs.

To measure silvicultural effectiveness, the ECS Program has established standard methods for three required assessments:

Assessment of regeneration[1] is required when a silvicultural system has been implemented to establish or recruit future crop trees. For prospective studies the normal timing is to assess regeneration prior to treatment and after a minimum of 5 full growing seasons post-treatment.

- Trees per acre is the standard measure of density of each species.
- Percent presence in sample plots is the standard measure of site occupancy for each species.
- Standard size classes for TPA tallies are: regenerants (<1" diameter and <1 foot tall); seedlings (<1" diameter and >1 foot tall); saplings (1-3" dbh); small trees (3-5" dbh).
- Basal area is measured for all tree species individually of any diameter
- The ECS Regeneration Plot Worksheet V2.0 2011 is the standard field form, and completed sheets are to be scanned and sent to the ECS Program Consultant.
- The ECS Program is responsible for entering the data into an archival database, providing standard regeneration reports to the forester who collected the data.
- See Procedure for Measuring Regeneration on p. 8 for instructions and the field form the field form is attached at the end of this document.

[1] It's important to recognize that the ECS regeneration assessment (e.g. plot design, data collection, and data management) does not follow regeneration procedures and standards as described in the Division Regeneration Monitoring document. For questions, contact your Regional Silviculturalist.

Assessment of growth is required when a silvicultural treatment is aimed at release or improved growth of residual trees. Measurement should occur at least 5 years after release. The benchmark of growth is an equal number of years before treatment and following treatment.

- The difference between average radial increment before and after treatment is the standard measure of growth improvement or decline.
- Annual radial increment by year is retained in order to plot trends following release.
- Up to 4 treatment conditions (amount or azimuth of release) can be recorded on the field form or alternatively, measured as residual BA around the tree and later grouped into classes.
- Tree condition is recorded in 4 standard mechanical damage categories, or any number of categories related to disease or pest damage.
- Release angle and azimuth are graphically retained as well as the azimuth of the tree core on the field form.
- The ECS Radial-growth Worksheet V1.0 2009 is the standard field form, and completed sheets are to be scanned and sent to the ECS Program Consultant.
- The ECS Program is responsible for entering the data into an archival database (In Progress).
- See Procedure for Monitoring Radial Growth on p. 22 for instructions and the field form is attached at the end of this document.

Monitoring plant diversity is highly recommended for all case studies. It is required when the silvicultural treatment includes site preparation, because the point of site preparation is to alter the groundlayer in a way that diminishes competition with planted trees or advance regeneration.

- Vascular plant species richness is the standard measure of diversity
- Species richness is measured at 11 different scales using a nested plot design.
- Native, introduced, and invasive plant status is tracked
- The ECS Species-area Plot Worksheet V1.0 is the standard field form.
- The ECS Program is responsible for entering the data into an archival database, providing standard regeneration reports to the forester who collected the data.
- See Procedure for Measuring Plant Diversity on p. 29 for instructions and the field form is attached at the end of this document.

Submitting Data

Legible copies or scans of ECS worksheets are to be sent to the DNR Resource Assessment office for quality-control and entry into an archival database. Please include supporting materials as well: timber sale records, written prescription, site photos, SRM reports, etc. so that they can be archived.

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Upon receipt, each case-study treatment or control plot or benchmark sample is assigned a unique tracking number. This number is used as a unique identifier in the Access database, and is used as the folder name that holds all pertinent documents in both paper form and on the computer. The databases or folders are available upon request at the same address above.

Submitting a Completed Case-study

The Great Lakes Silviculture Library is the repository for completed case studies. This is a Website managed by Eli Sagor of the University of Minnesota.

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Submissions are to follow a standard template that makes it easier to organize on Web pages. The standard Word template can be downloaded at this address: https://silvlib.cfans.umn.edu/content/submit-case-study

DNR field foresters are to download and use the Word template to organize their site information, prescription, results, and thoughts. DNR foresters will then submit their completed template to the Silviculture and ECS Program for review and editing. Submissions must include the Native Plant Community of the site and a quantitative assessment of results.

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Procedure for Measuring Regeneration/BA

Objectives

In prospective case studies, there are four main objectives that regeneration plots can address for each species in the stand:

Accurately estimate the number of regenerating trees per acre before and following a silvicultural treatment. The general goal is to estimate the population trends of the species and then conclude whether the treatment had a positive or negative effect. Also, we want to know if the treatment in general resulted in adequate stocking (site occupancy) of the site and compare results among different case studies[2].

Understand the timing and pattern of recruitment. For each species, comparing density by diameter class will help to understand how predictive diameter is concerning the survival of advance regeneration. Also, we want to understand how long it takes for regenerants and seedlings to recruit to small tree size (free-to-grow).

Understand how regeneration of one tree can affect the establishment of another. The purpose is to understand how tree seedlings relate to each other, i.e whether they have a positive, negative, or benign relationship because of a similar or dissimilar reaction to the treatment.

Measure the BA of residual trees and how that affects regeneration. BA is the coarse abundance measure of the residual canopy or seed trees. We want to understand how shade can influence the composition and recruitment of young trees.

In retrospective case studies, there are two main objectives that regeneration plots can address for each species in the stand:

Estimate the number of regenerating trees per acre as a general measure of success of a silvicultural treatment up until the point when initial-cohort trees are expected to have diameters >5 inches.

Understand the relationship between stand age and growth-stage. In older stands, disparity or similarity between overstory trees and advance regeneration <5 inches dbh is a rough measure of stand growth-stage.

[2] [2] Refer to Appendix A of the Division Regeneration Monitoring Procedures and Standards for trees per acre and stocking benchmarks for common forest cover types.

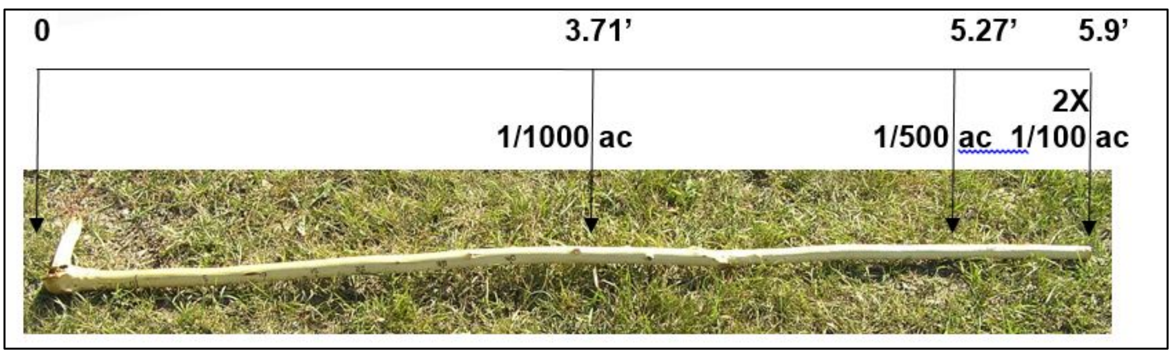
Field Procedure for Installing Regeneration/BA Plots

Step 1: In the office, create any GIS covers needed to distribute samples and load them into a GPS. For regeneration/BA plots a standard grid of points can be loaded for the desired sampling density. We recommend a plot per acre in stands under 30 acres. For stands 30-100 acres, we recommend a plot per 2 acres. If you do not plan to use a GPS it is useful to know that a 1-acre grid has points separated by about 3 chains (3.16ch), which for average people is about 40, two-step paces. A 2-acre grid has points separated by about 4.5 chains (4.47ch), which is about 58, two-step paces.

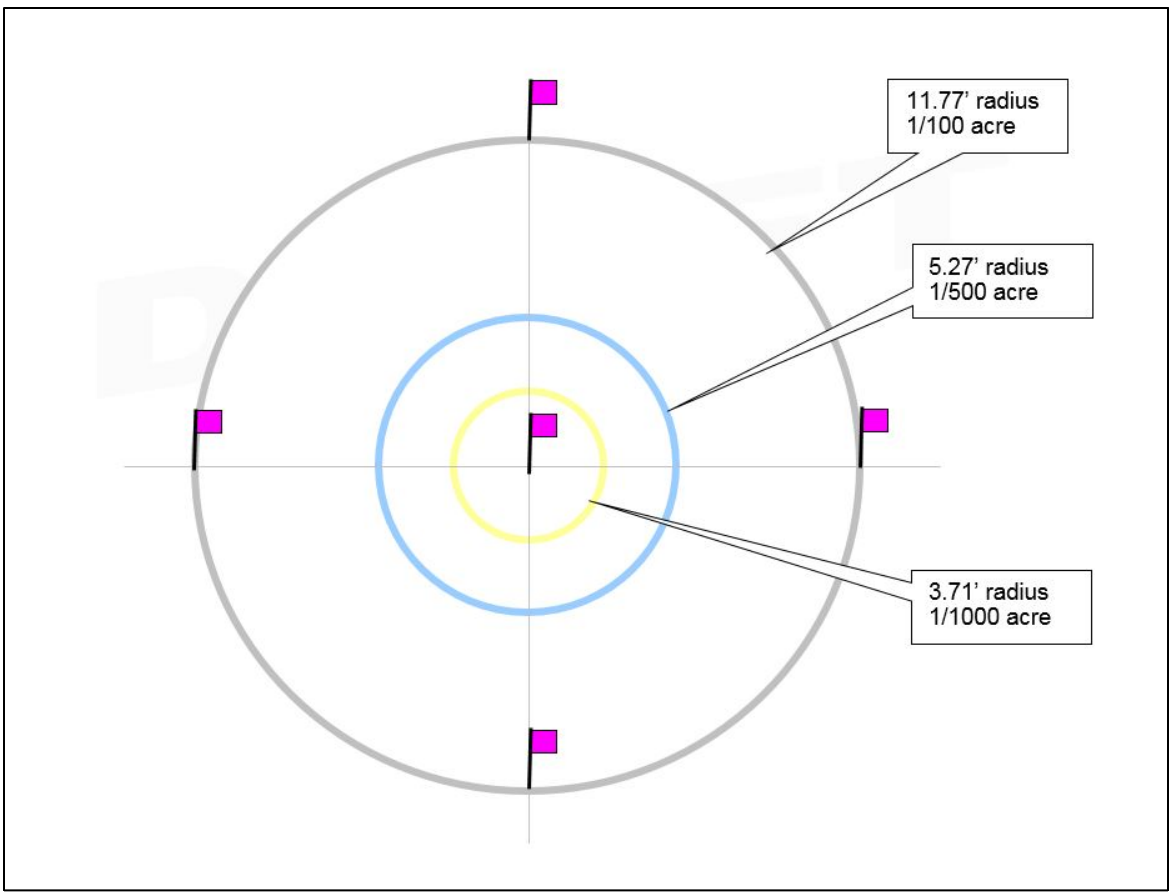
Step 2: Before going into the field assemble the necessary equipment: air photo(s), GPS, 5 wire flag-pins, layout stick, flagging, ECS Regeneration/BA Plot Worksheet, small stapler or paper clip, and a BA prism.

Typical Layout Stick

A layout stick is 5.9 feet long (5' 10 3/4"), with a marks at 3.71' (3' 8 ½") and 5.27' (5' 3 ¼") from one end. The stick may be outfitted with a terminal "L" whereby the tree in question can be "hooked" (as one might do with a carpenter's square) and its diameter read to place it in the right diameter class (<1", 1-3", 3-5"). Alternatively, the stick can just be marked at 1", 3", and 5" from the end.



Step 3: At each grid point locate the plot center and place a wire flag-pin. Place the end of the layout stick next to the center pin and flop the stick over on line and place a wire flag-pin at the end of the stick, 11.8' from the origin. Repeat this process for each quadrant. Use a compass or the right angle of a tatum to turn the 90^{o} angle if half- or quarter-plots are to be used in dense regeneration. The example below is typical of what we use in mature forests. Any size plot can be used for any diameter class depending upon the existing density of regeneration or planting keeping in mind the goal of getting at least a few regenerants, seedlings, saplings, or small trees in the plot. <u>Plot size MUST be recorded on the field sheet and if working in separate crews every crew MUST use the same plot sizes.</u>



Typical Layout of a Regeneration Plot in Mature Forest

Step 4: At the top of the ECS Regeneration Plot worksheet record the basic plot information beginning with: the names of the people collecting the data, the NPC code from the field guide, a site name, the date, and the factor of the variable-radius prism used to measure BA from the center of the fixed-radius plot.

Provide a brief description of the actual treatment that will allow the sample to be matched to the prescription.

Comments are collected throughout the sampling and should include: co-workers names, factors obviously affecting regeneration (slash, brush, browse), general impression of species with newly established seedlings (germinating, sprouting), and any flagging or painting done to expedite re-sampling., etc.

Regeneration/BA Plot Worksheet[1]	Version 2.0 2011 John Almendinger	Plot:	(leave blank)	
		NPC Code:		
		Site Name:		
Name(s):		Date:	/ /	(e.g. 21 JUN 2011)
Treatment:		Prism Factor/units:		X, ft^2 / m^2 (circle units)
		Number of plots in stand:		
		Subplot Coordinates		
		PL	Easting or Longitude	Northing or Latitude
Comments:		1		
		2		
		3		
		4		
		5		
		6		
		7		
		8		
		9		
		10		

Step 5: As sampling proceeds, record the GPS coordinates of every plot taken, and provide the sum of all plots when sampling is concluded. UTM, NAD 83, extended Zone 15 coordinates are preferred because that is the standard for the regeneration database.

Step 6: Four size classes of regenerating trees are recorded in the same manner, in four similar data block on the field sheet. Competing shrub stems can be counted on the field sheet, but they will not be entered into the database.

Regenerants are trees <1" dbh and <1 foot tall. Even recent germinants with cotyledons attached are counted as regenerants.
Seedlings are trees <1" dbh and >1 foot tall.
Saplings are trees 1-3" dbh.
Small trees are trees 3-5" dbh.

Based upon the existing density of trees in these four size classes, decide what sized plot will be used to sample them and record those sizes at the top of all four data blocks.

Step 7: Record the species and tally stems for regenerants, seedlings, saplings, and small trees at each plot before moving on to the next plot. (See next step if BA is to be recorded.) Total the tally and clearly write the number in the colored column for that plot.

Step 8: When completed, sum the row numbers and place the result in the Total column. Calculate and record the trees per acre (TPA=Total*fractional acre denominator of a plot/number of plots in a stand).

Example for regenerants, 1/1000th acre plot and ten plots in stand ⇓

Regenerant Block – trees <1" dbh and under 1' tall | **Plot size:** 1/ 1000 th of an acre (enter denominator)

Species	1	2	3	4	5	6	7	8	9	10	Total	TPA[1]
Sugar maple	13	22	16	15	9	11	23	13	15	12	149	14,900
Basswood	5	3	1		6	1	7		2		24	2,400
Q. Aspen	1		7	4	3	7	2	12		11	47	4,700
B.T. Aspen		4		1	2		8		3	13	31	3,100
Black Ash			2	5		3		2			12	1,200
e.g. Blk. Ash	1	5	4	8	2	7	10	3	6	9	55	

Step 9 optional: If the treatment left residual trees on the site basal area (BA) is useful for relating BA to regeneration success or radial growth increment for the stand following the thinning. Holding the prism over the center flag, count the number of "in" trees <u>by species</u> and record the total in the prism column. Be sure that the prism factor and units have been recorded on the top of the starting worksheet.

When finished, sum for every species the number of in-trees and record that in the Total column. Calculate the basal area of that species (BA=Total*prism factor).

Step 10 optional: If the treatment will leave trees >3" dbh one can paint or flag the trees to assist in relocating the plots for re-measurement. This is not required because for some other treatments one may want to re-distribute regeneration plots by harvested and leave areas differently depending upon the pattern of removal. Painting just the side of the residual tree facing the plot center allows for quite accurate re-establishment of plot centers.

Step 11: Note that several sheets will be required to sample stands over about 10 acres. <u>Use the continuation data sheet for extra plots</u>. This sheet omits the basic site information fields, but <u>it is critical that the site name, date, and page numbers be recorded</u> so that the set of sheets for a sampling can be assembled should the sheets become separated.

Step 12: In the field, check to be sure that all information has been recorded. It is good practice to staple or clip the set of sheets together in order at this time.

Step 13: Back at the office, photocopy or scan the field form and file a copy where you can find it. Mail the original copy or e-mail a legible scan to the address shown on starting worksheet for data entry.

Analysis and Use of Regeneration/BA Plot Data

Tracking the density of small diameter trees before and after a treatment tells us about establishment, mortality, and occupancy by species. The difference between pre-treatment and 1st growing-season post-treatment density is mostly a measure of incidental mortality associated with the treatment. The difference between the 1st and 5th growing season density records establishment and mortality due to post-treatment site conditions. For treatments that leave areas of intact forest (leave patches) the results are partitioned into treated or leave categories for direct comparison over short distances and also, to understand how leave patches pass on legacy elements to the treated areas.

The easiest way to display the data is in a summary table, one for each diameter class showing the pre-treatment density and the density after 1 and 5 growing seasons. Table a. is an example from a northern hardwood stand for the 0-1" diameter class. Identical tables would be constructed for the 1-3" and 3-5" diameter classes.

Table a. Density (n, trees per acre) and proportional population change (Δp) of tree seedling (<1" diameter) density between sampling intervals. Post-treatment results are partitioned into plots within the treated area and plots within leave areas. In parentheses are the number of 1/1,000th acre plots used to make the density estimates. The proportion of the current population to that of the previous population is calculated as: $\Delta p_{2005}=n_{2005}/n_{2004}$; $\Delta p_{2009}=n_{2009}/n_{2005}$. Treatment was a variable-density thinning where strips and openings were clear-cut (treated) within a matrix of undisturbed forest (leave), resulting in about 85% (29/34) canopy removal.

	Pre-treatment 2004	**Post-treatment 1st season, 2005**				**Post-treatment 5th season, 2009**			
		leave		**treated**		**leave**		**treated**	
	n (34)	**n (5)**	**Δp**	**n (29)**	**Δp**	**N (5)**	**Δp**	**N (29)**	**Δp**
Sugar Maple	**5,000**	**4,500**	**0.90**	**1,200**	**0.24***	**4,200**	**0.93**	**400**	**0.33***
Basswood	**150**	**160**	**1.06**	**65**	**0.43**	**170**	**1.06**	**70**	**1.08**
Red Oak	**50**	**60**	**1.20**	**65**	**1.30**	**125**	**2.08***	**85**	**1.31**
Ironwood	**30**	**10**	**0.33**	**5**	**0.16**	**15**	**1.50**	**8**	**1.60**
Quaking Aspen	**45**	**60**	**1.33**	**1,800**	**40.0***	**65**	**1.08**	**1,200**	**0.67**
White Pine	**15**	**20**	**1.33**	**25**	**1.67**	**30**	**1.50**	**27**	**1.08**
Total	**5,290**	**4,810**		**3,160**		**4,605**		**1,790**	
Significance of change: *p<.05									

Our **first objective,** accurately estimating the number of trees per acre, is achieved by simply having enough plots and direct counts of stems. As described in the procedure, 1 plot per 1-2 acres is considered adequate for most forest management treatments. In all cases the variance among the plots by set (34, 5, and 29 above) should be calculated and expressed/discussed when important (p<.05 above).

We want to also estimate population trends in response to treatment. Change between the pre-treatment and first-growing season is mostly an estimate of incidental mortality associated with treating the stand. Change between the first and fifth growing seasons is a measure of how advance regeneration is responding to the new site conditions. The proportion of the current population to that of the previous population (Δp) change between samplings is a good way to illustrate the magnitude of change for a species.

$\Delta p_{\text{due to treatment}} = n_{\text{pre-treatment}} / n_{\text{first-season}}$
$\Delta p_{\text{due to stand conditions}} = n_{\text{first-season}} / n_{\text{fifth-season}}$

Proportional change under 1.0 shows decline and proportional change above 1.0 indicates a population increase. For positive change, the number represents the x-fold increase, e.g aspen had a 40x increase in the treated area in 2005. For negative change, the inverse of the proportional change is the x-fold decline, e.g. sugar maple had a 1/0.24 = ~4x decrease in the treated area in 2005.

Estimating new establishment is also possible from the fixed-radius plot tables. A positive difference between the number of trees per acre now, and a previous sampling is an estimate of the net gain due to establishment. We do not require that newly established seedlings be tallied separately because it is difficult to do and results are inconsistent. However, it is useful to indicate on the data lines for the 1/1,000th acre plot if a species seemed to have significant new establishment, based upon small size or the presence of cotyledons. For example: “Sugar maple^{ge}” would indicate that on that plot, some of the <1” sugar maple seedlings were germinants. If you consistently do this, put that note in the comments because an informal interpretation as to seedbed response can be done by frequency among the 1/1,000th acre plots.

Our **second objective**, understanding how diameter relates to post-treatment survival and subsequent recruitment, is best illustrated in a table (Table b. below) that summarizes the proportional changes for species as derived from the diameter-class tables. Each table would be for the most recent sampling and usually just for treated areas of the stand.

Table b. Proportional change in species density by diameter-class between the 1st and 5th growing-seasons on treated portions of the stand. Treatment was a variable-density thinning where strips and openings were clear-cut (treated) within a matrix of undisturbed forest (leave), resulting in about 85% (29/34) canopy removal.

Species	Diameter-class		
	<1”	1-3”	3-5”
Sugar Maple	**0.33***	**0.79**	**0.91**
Basswood	**1.08**	**0.83**	**0.87**
Red Oak	**1.31**	**0.92**	**0.95**
Ironwood	**1.60**	**0.50***	**0.78**
Quaking Aspen	**0.67**	**1.23**	**1.02**
White Pine	**1.08**	**0.91**	**none**
Significance of change: *p<.05			

Our **third objective**, understanding the effect of other plants on tree establishment, is accomplished by calculating pair-wise associations of tree seedlings with other trees and plants. These data are collected only on the 1/1,000th acre plot because the plot must be small enough to assure interaction between the plants with regard to light and soil resources. The application is to help foresters recognize, prior to treatment, the likely competition or benefit that the groundlayer will have on regeneration.

Our standard measure of association is Cole's Coefficient of Association, but other measures with X^2 testing are also useful. Negative coefficients indicate antagonistic interaction (competition, alleleopathy), whereas positive coefficients indicate positive interaction (mutualism, symbiosis).

		Species B		
		present	absent	
Species A	present	a	b	a+b
	absent	c	d	c+d
		a+c	b+d	a+b+c+d=n

To calculate Cole's Coefficient of Association C_c:

1. For each species pair, arrange a 2X2 contingency table (above) such that species A does not occur in more samples than species B. i.e. (a+b) le (a+c).

2. Three different equations are used to calculate C_c and the standard error, Se_c, depending upon three mutually exclusive table conditions:

When a*d ge b*c, i.e. positive association

$$\mathbf{C_c \underline{+} Se_c = (a*d)-(b*c)/(a+b)*(b+d) \underline{+} sqrt((a+c)*(c+d))/n*(a+b)*(b+d)}$$

When b*c gt a*d and d ge a, i.e. negative association

$$\mathbf{C_c \underline{+} Se_c = (a*d)-(b*c)/(a+b)*(a+c) \underline{+} sqrt\ ((b+d)*(c+d))/n*(a+b)*(a+c)}$$

When b*c gt a*d and a gt d, i.e. negative association

$$\mathbf{C_c \underline{+} Se_c = (a*d)-(b*c)/(b+d)*(c+d) \underline{+} sqrt\ ((a+b)*(a+c))/n*(b+d)*(c+d)}$$

The resulting coefficients range from –1 to +1 with the negative numbers indicating negative association and positive numbers representing positive association. A coefficient is "significant" when it is so negative or so positive that zero is not within the range of standard error.

The calculations yield an incredible number of pair-wise scores which is equal to the number of species encountered in the 1,1000th acre plots squared, divided by two minus the number of species encountered. This is far easier to envision in a symmetric table (c.) where the trace holds the trivial, perfect correlation of a plant with itself.

Table c. Partial table of Cole's coefficients for species pairs in FDn43 forest based upon co-occurrence in releves. Range of coefficients rescaled from –1 to 1, to 0-200. The original dataset of 50 species with >5% frequency yielded a full table of (50^2/2)-50=1,200 non-trivial pair-wise coefficients.

	ABIE15BA	ABIE69BA	ACER15RU	ACER15S2	ACER69RU	ACER69S2	ACERSPIC	ALNUINCA	ARALNUDI	ASTEMACR	ATHYANGU	BETU15PA	BETU69PA	CALACANA	..	VACCANGU
ABIE15BA	200															
ABIE69BA	200	200														
ACER15RU	133	114	200													
ACER15S2	116	84	89	200												
ACER69RU	156	111	200	105	200											
ACER69S2	200	73	142	200	120	200										
ACERSPIC	61	86	67	162	109	200	200									
ALNUINCA	80	73	56	108	58	0	139	200								
ARALNUDI	106	139	135	80	100	37	95	93	200							
ASTEMACR	0	124	129	94	121	75	104	97	112	200						
ATHYANGU	104	87	88	113	95	0	162	151	126	122	200					
BETU15PA	101	86	133	105	156	92	112	132	60	94	104	200				
BETU69PA	91	106	104	153	171	200	123	124	35	97	136	132	200			
CALACANA	44	52	49	102	48	0	100	141	82	154	125	106	116	200		
:																
VACCANGU	140	115	151	66	139	0	70	66	169	151	43	135	87	66		200

Obviously, the analysis of association matrix needs to be simplified for any practical application for case studies. First, many coefficients can be eliminated based upon statistical significance. Just limiting consideration to coefficients at the $p<.05$ or $p<.01$ levels of significance greatly reduces the pairs of interest. Second, for most case-studies we are interested in the regeneration of just a few crop trees. Thus tables for individual species holding just statistically significant coefficients are manageable (Table d.).

Table d. Cole's coefficient of association of plants interacting with **white spruce** seedlings. All members have significant associations ($p<.05$).

Associate	Cole's Coefficient	Standard error
Apparently limiting		
Basswood seedlings	**-1.00**	**0.41**
Black spruce trees	**-0.62**	**0.17**
Black spruce seedlings	**-0.46**	**0.12**
Apparently beneficial		
Quaking aspen seedlings	**0.15**	**0.07**
White cedar seedlings	**0.28**	**0.13**
Thimbleberry	**0.47**	**0.13**
White spruce trees	**0.56**	**0.11**
Low-sweet blueberry	**0.15**	**0.11**

For case studies, we will have 3 calculations of Cole's coefficients: pre-treatment, 1st growing season, and 5th growing season. We also have a rough tracking of abundance changes of trees (TPA) or non-trees (1-4 quadrants). For any regenerating species of interest, we can track changes in the coefficient and abundance changes of the plant associates. In cases where the coefficient stays negative and the coefficient's value seems correlated with abundance of the plant associate – it is highly likely that the associated plant is a serious competitor and control efforts warranted. Conversely, if the coefficient stays positive and is correlated with abundance of the plant associate – it is highly likely that the associated plant is beneficial. Thus we would expect that planting the tree of interest among beneficial plants should work. Also, indiscriminant control of groundlayer "competition" could be a poor management choice if the groundlayer has considerable cover of beneficial plants.

Analysis of association probably has greater application beyond case studies. Data can be pooled by NPC Class and within Class by treatment. When enough samples have been pooled, the relationship of tree seedlings to other plants becomes part of understanding the community silvics of trees.

Our **fourth objective**, is to understand how residual trees affect the survival and recruitment of regeneration. This can be evaluated for a single treatment by examining the proportional change of each species in the 4 size classes (Table b. above).

However the BA of residuals provides a useful way of examining gradients of shade in a collection of case studies. For example one might collect all of the available case studies in the MHn35 community with similar advance regeneration but different intensities of partial harvesting. Theory would predict that the different species of trees under 5" will respond differently to the levels of residual shade. Alternatively, one might collect all of the available case studies in the MHn35 community with similar advance regeneration and similar levels of canopy removal, but differing in the species of trees left as residuals. We could then use change in abundance in the regenerant class as a measure of establishment success and consequently the effectiveness of leaving certain species as seed trees.

Procedure for Monitoring Growth

Objectives
Two measures of growth are useful in assessing the success of silvicultural treatments aimed at improved growth of residual trees.

Measure stand growth as a response to thinning. Measuring stand basal area (BA) before treatment, after 1 growing season, and after four growing seasons allows us to: characterize the composition of legacy patches, quantify the actual removal of trees, and calculate the increment in BA that presumably is the result of the thinning. Variable radius ("prism") plots are a quick and fairly accurate method of estimating BA. BA data can be pooled by species to compare the reaction of different kinds of trees to the treatment, or they can be pooled by treatment.

Measure mean growth of different species as a general response to the thinning regime. The annual increment of individual tree growth is determined from growth-rings and pooled by species. The thinning regime is defined by one or several standard measurements such as: residual basal area, sides released, or damage classes. The main purpose is to accumulate such data from several case-studies and develop some benchmarks of tree response to thinning. The application is to use different thinning regimes to affect the outcome of post-thinning competition among the species.

Measure the growth of individual trees in post-thinning categories associated with the sale design. Radial growth of individual trees is interesting when fine-scale pattern within a stand is important. Trees are placed into treatment categories (e.g. gap, leave, edge, next to skid trail, etc.) and their annual rings are used to calculate mean increment prior to treatment and annual increment after treatment. Increments are pooled by category and species to assess the effect of the treatment on growth.

Define recovery period for species in post-thinning categories. Release or damage can depress increment and stress trees to the point where insect and disease problems arise. We want to understand how long it takes for trees to recover (if at all) and to start accumulating increment in excess of their pre-treatment production (if ever).

Field Procedure for Installing BA Plots

The procedure for installing and completing BA plots is covered in the Procedure for Measuring Regeneration section, using the Regeneration/BA Worksheet.

Analysis and Use of Stand-growth (BA) Data

Stand basal area is best organized in a table with rows for each species and columns for the BA estimates and any derived calculations such as change or proportional change. Below is an example (Table e.) from a thinned northern hardwood stand that was initially measured in 1997, eventually thinned in 2001, and then re-measured after 1 and 5 full growing seasons.

Table e. Basal area(BA, ft^2 per acre) and change in basal area (Δ, ft^2 per acre) between the untreated stand and 1 growing season after thinning, and between 1 and 5 growing seasons after the thinning. Post-treatment results are partitioned into plots within the thinned area and plots within leave areas. In parentheses are the number of variable-radius plots used to make the BA estimates. Treatment was an even thinning aimed at removing aspen and poor sugar maple and basswood to favor red oak, and white pine. Some un-thinned leave patches were created where there was more red oak and white pine. About 78% (11/51 plots) of the stand thinned.

	Pre-treatment 1997	Post-treatment 1st season, 2002				Post-treatment 5th season, 2006			
		leave		treated		leave		treated	
	BA (51)	BA (11)	Δ	BA (40)	Δ	BA (11)	Δ	BA (40)	Δ
Sugar Maple	40	37	-3	20	-20	44	+7	29	+9
Basswood	23	27	+4	13	-10	30	+3	19	+6
Red Oak	25	33	+8	27	+2	35	+2	38	+11
Ironwood	2	3	+1	0	-2	5	+2	0	0
Quaking Aspen	35	12	-23	5	-30	7	-5	6	+1
White Pine	17	28	+11	13	-4	31	+3	24	+11
Total	142	140	-2	78	-64	152	+12	116	+38

A component of our **first objective** is to characterize the composition and BA of any leave patches. This is done by comparing BA of the leave patch with pre-treatment conditions. This provides a measurement of bias in selecting the leave patches from the original forest matrix. When considered in conjunction with the regeneration data, it will give us a sense as to how effectively the leave patches served as a legacy source for re-colonizing the treated areas. In this case the leave patches were located to leave legacy red oak and white pine seed trees and to avoid places where aspen was abundant or in decline.

A second component of our **first objective** is to define the actual removal associated with the prescription. Comparing BA before and one growing-season after treatment allows us to summarize the removal. The first post-treatment BA measurements are the benchmark for calculating change in BA resulting from the treatment for all future measurements. In the example the goal was to remove all aspen and poor quality sugar maple and basswood. The condition of the stand essentially dictated the thinning intensity which ended up removing 64 ft^2 and leaving 78ft^2.

The main component of our **first objective** is to quantify BA increment that has resulted from the treatment. Subtracting the first growing-season BA from BA after 4 post-treatment growing seasons is stand increment. For a single case study the raw BA numbers and change are informative (above). To compare case studies where different years (or span of years) are involved, conversion of the raw numbers to mean annual increment is necessary (below). In the example it seems that mean annual increment (MAI) in the thinned portion of the stand (+9.5 ft^2) was considerably more than in the leave areas (+3 ft^2).

Different reactions to thinning among the species are evident in the proportional change calculations. In the example, the tolerant sugar maples added more BA in the leave patches than any other tree (+7ft^2), but that result is at least partially due to the fact that there were likely more sugar maple trees (44 BA) than others. The ratio of gain to starting BA (7/44, Δp) does allow for direct comparison where it seems that sugar maples trees did show more radial growth than the other species except for the dubious (low sample) growth of ironwood. In the treated area, all northern hardwoods performed about the same (Δp +0.29-0.31), better than quaking aspen (+0.16) and poorer than white pine (+0.46). Thus, the thinning seemed to have the desired effect of increasing total increment (+38>+12) and allowing mid-tolerants to keep up (red oak +0.29) or exceed (white pine +0.46) the growth of the dominant sugar maples.

	Summary of BA growth over 4 growing seasons, 2006							
	leave				treated			
	BA (11)	Δ	MAI	Δp	BA (40)	Δ	MAI	Δp
Sugar Maple	44	+7	+1.75	+0.16	29	+9	+2.25	+0.31
Basswood	30	+3	+0.75	+0.10	19	+6	+1.50	+0.31
Red Oak	35	+2	+0.50	+0.06	38	+11	+2.75	+0.29
Ironwood	5	+2	+0.50	+0.40	0	0	0	0
Quaking Aspen	7	-5	-1.25	-0.71	6	+1	+0.25	+0.16
White Pine	31	+3	+0.75	+0.10	24	+11	+2.75	+0.46
Total	152	+12	+3.00		116	+38	+9.50	

Field Procedure for Monitoring Radial Growth of Residual Trees

Step 1: In the office, create any GIS covers needed to distribute samples and load them into a GPS. For new case studies, the first growing season air photos will be useful for setting up the treatment categories to be associated with the trees to be measured, e.g. leave, gap, thinned, skid trail, etc.

It is good practice to set-up the treatment matrix before going into the field. The treatment matrix is set by the number of species of interest and the number of number of treatment categories in which we want to measure the growth of those trees. For example, a variable density thinning might consist of clear-cut gaps, clear-cut paths, and leave areas of intact forest. We suspect that trees on the edge of gaps will grow better because they should experience greater amounts of light and less competition on one side. Trees on the paths could be adversely affected by heavy-machinery traffic, or they could react much as the gap-edge trees. We would want to also measure the growth of trees on the interior of the leave matrix for comparison to trees on the gap and path edges. If the stand consisted of quaking aspen, paper birch, balsam fir, and white spruce. Then the treatment matrix would be a 3-condition by 4-species matrix consisting of 12 different treatment/species cells.

	Gap edge	Path edge	Interior
Quaking aspen			
Paper birch			
Balsam fir			
White spruce			

Treatment categories can be modified in the field based upon existing conditions. For example, if is\t was obvious that lots of trees on the paths were damaged by skidding, then we might want to divide the path edge treatment into patch intact and path edge damaged categories should we want to know the effect of obvious damage. This would create a 4-condition by 4-species matrix with 16 treatment/species cells.

	Gap edge	**Path edge intact**	**Path edge damaged**	**Interior**
Quaking aspen				
Paper birch				
Balsam fir				
White spruce				

The purpose of considering the treatment-species matrix is so that you know when you have collected enough tree cores to balance the matrix. We suggest a minimum of five cores per combination of species and treatment category. For the 4x4 table this would mean that 80 cores would be collected.

After constructing the matrix, one should pick evenly distributed spots where one should be able to find enough trees to core and fill the sampling matrix.

Step 2: Before going into the field assemble the necessary equipment: air photo(s), GPS, dbh tape, increment borer, storage straws and canister, permanent marker, ECS Radial-growth Worksheet, and BA prism.

Step 3: At the top of the ECS Radial-growth worksheet (below) record the basic plot information beginning with: the NPC code from the field guide, a site name, your name, and the date. Record the starting coordinates of the first tree cored. The starting coordinates are very important as the <u>coordinates, not the site name, are what ties the worksheet to the stand</u>. Record the season and month of the treatment and describe it in enough detail so that the treatment classes are understood. Record also the species of interest in the tally matrix and the known treatment classes. Comments are collected throughout the sampling and should include: co-workers names, factors obviously affecting growth, and any notes that would later clarify which cores belong to which trees.

Radial-growth Worksheet		Version 1.0, 2009 John C. Almendinger	**NPC Code:** **Site Name:**			
Name:		**Date:** / / (mm.dd.yyyy)				
Coordinates of initial tree cored		**Tally Matrix**	**Treatment**			
Easting:	**Northing:**	**Species**	**1**	**2**	**3**	**4**
Lat:	**Long:**					
Treatment						
Year:	e.g. summer 1992					
Description:						
		Treatment Legend	**1=**			
Comments:			**2=**			
			3=			
			4=			

Step 4: Start entering tree records by defining the tree's environment (below).

Tree Environment				
TC	**CC**	**CR**	**RBA**	**RIs**
2	HE	30%	50	
3	BL	20%	80	

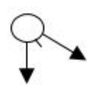
TC is the "Treatment Condition" as defined in the Treatment Legend. Use the numbers 1-4 as defined. If more treatment classes are needed, document these and their numbers in the comments section.

CC is the condition class of the tree. One of the major concerns of thinning and TSI prescriptions is the damage done to the residual trees. One must decide in the field if enough damage has been done to warrant a new treatment class. Otherwise, try to select healthy trees and when you can't record the kind of damage in this field. The basic classes are: HE=apparently healthy, BL=broken leader, BB=broken branches, RT=roots trampled. If other kinds of damage or disease are noted, reference your coding system in the comments section.

CR is the tree's crown ratio. Visually estimate the proportion of living crown to total tree height to the nearest 10% and enter that number.

RBA is the residual basal area of trees around the tree that will be cored. Count only the trees of equal or larger size and enter the square feet per acre in this column.

Rls is a graphic that shows the side and extent of crown release and where the core was taken.



Release between ~110-180º
Core on SE side

Release between ~215-115º
Core on NE side

Total Release ~all sides
Core on SW side

No release ~no sides
Core on NE side

Step 5: Record the basic information concerning the tree core.

Species: is the common or scientific name of the tree.

DBH: is the diameter of the tree at breast height in inches.

Str #: is the number of the protective straw that will hold the tree core as it is transported back to the office for measurement.

Core		
Species	**DBH**	**Str #**
White pine	**9"**	**132**
Quaking aspen	**5"**	**63**

Step 6: As trees are cored, keep a tally of species and treatments for which cores have been collected. When you have collected enough cores (~5) and balanced the treatment/species matrix, the field collection is complete.

Tally Matrix	**Treatment**			
Species	**1**	**2**	**3**	**4**
Balsam fir	~~IIII~~	~~IIII~~	~~IIII~~	
Quaking aspen	~~IIII~~	~~IIII~~	~~IIII~~	
White spruce	~~IIII~~	~~IIII~~	~~IIII~~	

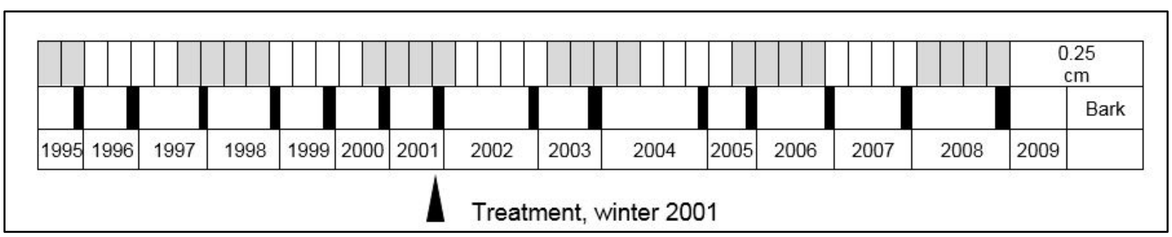
Treatment Legend	
	1=large gap
	2=small gap
	3=leave patch
	4=

Analysis and Use of Radial-growth Data

Step 7: Back in the office, the field sheet needs to be set up to record the increments. We are interested in full annual increments, which for this application consist of spring/summer wood ("summer wood") and wood produced as the following winter/dormant season approached ("fall wood"). For example, a core collected in July 2009 will not have fall wood for that increment, so then the core would be trimmed back to fall wood and the last full increment would be for the 2008 growing season and the fall/winter of 2008-2009 – 2008 is thus the first full increment. A core collected around March of 2009 would have fall wood and could be counted as a full increment – 2009 is thus the first full increment. Having determined the first, full-increment year, put that year into the leftmost column for recording increment. Add years in descending order until the last full increment following the treatment has been recorded. Now, knowing the number of full-increment years after treatment, set up a column for the same number of years before treatment so that increment pre- and post-treatment can be compared. Below is an example with 7 full post-treatment increments.

Growing-season Year & Increment (to 1mm)														
2008	2007	2006	2005	2004	2003	2002	2001-1995							**e.g. 2009**

Step 8: Having set up the field form for measuring increments, the increments to nearest mm are recorded in the cells. Below is a table depicting a tree core in the middle row, with summer wood white and fall wood black. The bottom row shows the annual increment assignments and the top row is a scale bar in increments of ¼ cm.



Given the example of a core above, below are the records that would be recorded on the field sheet.

Growing-season Year & Increment (to 1 mm)														
2008	2007	2006	2005	2004	2003	2002	2001-1995							**e.g. 2009**
11	8	9	5	11	7	10	44							

For radial-growth data we are interested in how different species of trees react to different situations after thinning. Understanding differences among the species contributes to our understanding of how residual density and pattern of removal favors one species over another. Understanding differences in a tree's location relative to the thinning design (gap, edge, interior, residual BA) or by damage categories associated with logging (broken tops, skinned trunks, skid trail compaction, etc.) can help us understand if some sale designs are more conservative of growth and collateral damage.

Species data can be interpreted summarized in an organized table to meet our **second objective**. Our methods call for balancing the post-treatment increment and increment for the same number of years prior to treatment. If this is done then total increment is all that is needed in the table. If this is not possible then calculating annual increment is required for comparison. The important numbers in the table are the species' difference in increment during the post-thinning years and previous years. Positive numbers indicate improved growth due to the thinning. Annual increment allows for comparison among different case studies. The units of increment can be changed to suit particular audiences. In the example below (Table f.), quaking aspen, balsam fir, and white spruce all showed improved growth after thinning, but fir reacted more positively than the others. Declining growth (negative difference) is possible if exposure stresses trees. In this case it seems that the effect of the treatment on paper birch was to reduce growth at least for the first 7 years.

Table f. Mean total increment for 7 years of growth pre- and post-treatment. The difference between post-treatment increment and pre-treatment increment allows comparison of species' reaction to thinning – positive numbers indicating more growth due to thinning. Shown also is mean annual increment, which adds no further information, but is useful for comparing case studies where the actual years or span of years differ from one case-study to another.

	Total increment (cm)			**Mean Annual Increment (mm)**		
	pre	**post**	**Δ**	**pre**	**post**	**Δ**
Quaking aspen	1.30	1.52	+0.22	1.86	2.17	+0.31
Paper birch	1.03	0.97	-0.06	1.47	1.38	-0.09
Balsam fir	0.73	1.21	+0.48	1.04	1.73	+0.69
White spruce	1.01	1.19	+0.18	1.44	1.70	+0.26
Totals	4.07	4.89	+0.82	5.81	6.98	+1.17

Understanding the growth of tree species by post-thinning category, our **third objective,** is done by ANOVA testing of mean increment by treatment/situation category. The preliminary treatment categories vary depending upon the pattern and removal of trees on any individual thinning strategy. In the field, treatment categories can be added if necessary. Because we anticipate pooling data from several case studies (by NPC Class), it is possible to create a variety of categories and we have added several variables that describe tree situations to facilitate re-classification: condition class, crown ratio, residual basal area, and release (open sides and azimuth). In all cases, analysis involves the artful and iterative process of creating or dissolving classes to achieve an ANOVA table with few categories and high statistical significance.

Table g. (below) summarizes an ANOVA analysis of how radial growth differed among species and treatment classes resulting from a “string of pearls” thinning. In this treatment circular gaps ~50’diameter were cut out of the continuous canopy on a grid with gap centers ~2 chains apart, and trees on the edge of these gaps were assigned to the gap class. Paths ~15’ wide were cut to allow the harvester to move from gap to gap, and trees on the edge of paths were assigned to the edge class. This removal leaves about 50% of the canopy between strings of paths and gaps, and trees near the middle of these leave strips were assigned to the interior class. In the field, it was noticed that trees along the paths were often damaged, so a damaged class was added to the analysis. Analysis was limited to the dominant residual trees: paper birch, white spruce, and quaking aspen.

Table g. Mean annual increment (mm) of trees by treatment class. For each species and all trees combined, the R-square values are an estimate of the amount of variation in growth that seems to be explained by the groupings. The P-values indicate the likelihood that the groupings are not different from a random sample of increments from the stand. Tukey's Studentized Range (HSD) Test is presented below each species and for all trees together. This test groups the treatment categories that have mean increments that are <u>not</u> different from each other at the P<.05 level, i.e. the means are less than the “min sig” value apart. Cells are shaded to emphasize the Tukey groups; however, the shading and group assignments do not indicate the same thing for each species.

	gap	edge	interior	damaged	R-square	P-value
All trees	2.46	2.16	1.57	0.89	0.637	<.0001
tukey groups	A	A	B	C	Min sig= 0.4539	
Paper birch	2.58	2.14	1.50	0.60	0.747	<.0001
tukey groups	A	A/B	B	C	Min sig=0.8748	
White spruce	2.08	2.02	1.82	1.06	0.556	0.0039
tukey groups	A	A	A	B	Min sig= 0.7345	
Quaking aspen	2.72	2.32	1.38	1.00	0.734	<.0001
tukey groups	A	A	B	B	Min sig=0.8419	

In the example above, trees generally had greater radial growth in the gap and edge classes (all tree class). For all species, the gap edge was better than the path edges, but not significantly so. Species order of improved growth in the gap and edge classes was the same: aspen>birch>white spruce. This order matches the species’ tolerance ratings and one might conclude that thinning patterns that create as much edge habitat (2-sided release) as possible would favor intolerant species over tolerant ones in mixed stands. In the leave interiors, the growth-order is reversed: white spruce>birch>aspen. If one wanted to favor white spruce over aspen and birch, one might guess that a thinning pattern that retains some interior character would be best – perhaps even thinning with no more than 25% removal (~1-sided release). For all trees damage significantly diminished radial growth.

Our **fourth objective** is addressed by plotting the annual departure from mean pre-treatment increment. Such graphs can be constructed for individual trees or the data can be pooled by species, post-treatment situation, or condition class. Usually, the most useful pooling of data is evident from the ANOVA results. In the above example (Table g.) were seemingly useful categories for explaining growth-differences and can be used to construct the legend for a plot of annual increment departure from the pre-treatment base MAI (Figure a).

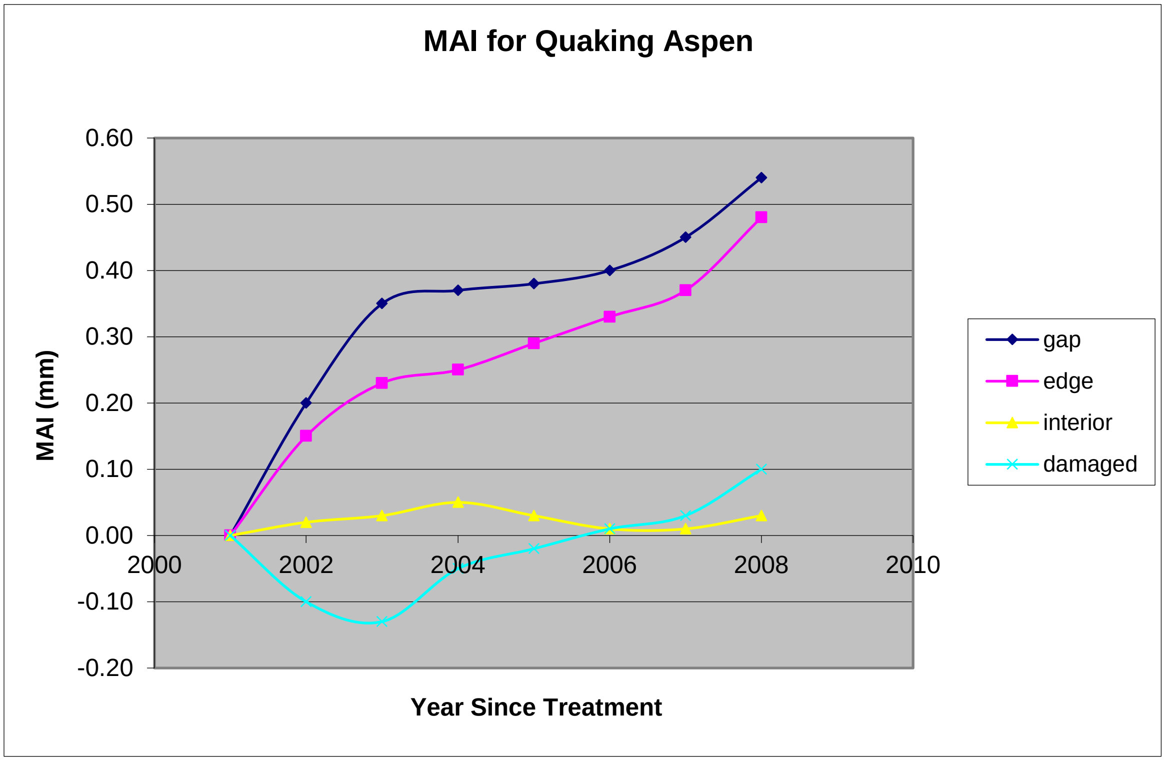


Figure a. Departure of annual increment from mean pre-treatment increment in 2001 for quaking aspen.

The primary advantage of plotting annual departures from mean pre-treatment increment is to get a feeling for recovery periods that are obscured by calculating means over several years. In Table g. it is clear that damaging trees is a significant concern as all species showed poorer radial growth on damaged trees over the full 7-year post-treatment period. In Figure a. the annual plot for quaking aspen confirms the growth decline, but it also shows that the trees had recovered by 2006 and were starting to show improved increment not much different from the gap and edge trees and better than interior trees.

Procedure for Monitoring Plant Diversity

Objectives
There are five main objectives that species-area plots can address.

Define "benchmark" levels of plant diversity for each NPC Class. Benchmark levels will be compared to post-treatment measurements in cases where we can't obtain pre-treatment measurements (retrospective studies).

Define the scale of plant diversity. Species-area plots can help us understand how large legacy patches need to be to conserve 70%, 80%, 90%, etc. of the plants likely to be in the stand.

Understand the rate of re-colonization and development of fine-scale pattern of groundlayer plants. Species-area curves provide a means of measuring recovery, which must occur between entries in order for a treatment or silvicultural system to be sustainable.

Infer the effect of the treatment on the forest ecosystem. While it is possible to measure the effects of timber harvesting on the non-living elements of a forest ecosystem, it is incredibly time-consuming and expensive. Because the NPC Classes are associated with some physical factors, shifts in species composition from one Class towards another allows us to guess as to whether a treatment has caused the site to become wetter, impoverished, warmer, etc. Such shifts will provide clues as to what instrumentation might best measure physical site impacts should the treatment be repeated.

Document the ingress or spread of invasive plant species. While species-area plots are not particularly sensitive to measuring ingress or changes in plant populations, they at least document what happened in a 1024m^2 patch of the forest.

Field Procedure for Installing Permanent Species-area Plots

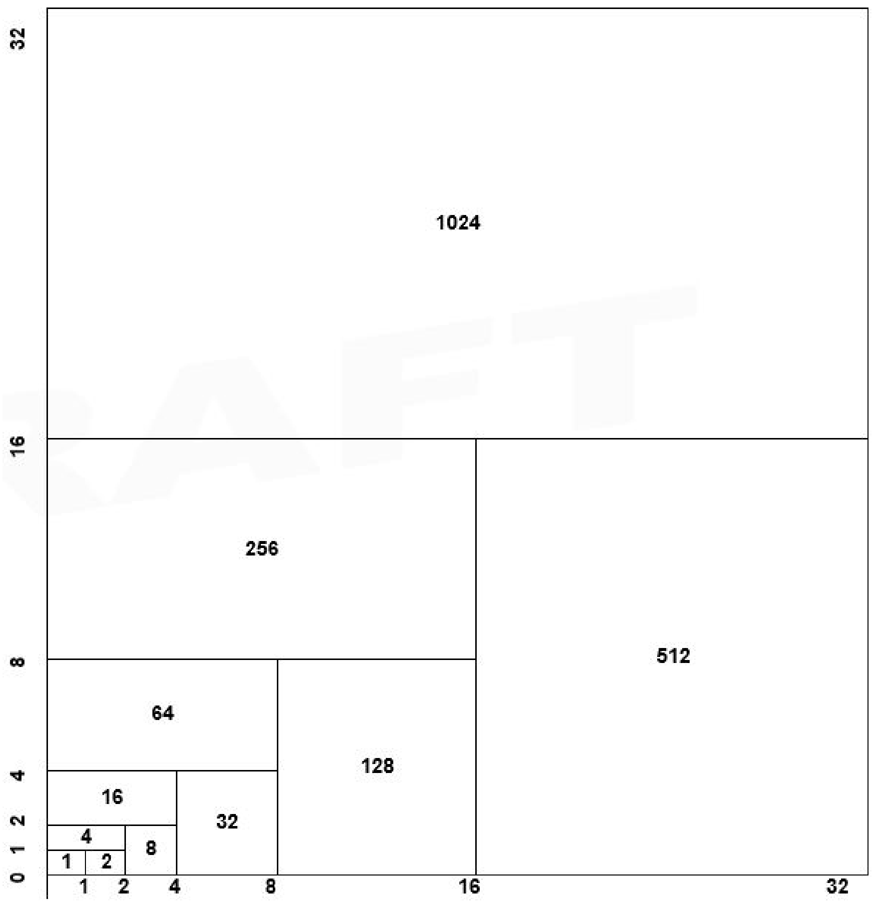
Step 1: Before going into the field assemble the necessary equipment: 24 wire flag-pins, a meter tape at least 32m long, surveyor's magnet, ECS Program Species-area Plot Worksheet. The flag-pins must be durable because they will often be trampled by heavy equipment and must stay in place for at least 5 years.

Step 2: Before going into the field, examine the air photo for the stand that is to be treated. Identify potential plot locations, which should be centered in patches of the canopy that seem to have a uniform signature typical of the stand's NPC Classification. If possible, generate GPS waypoints for the candidate locations.

Step 3: In the field, select a plot location from among the candidates that is homogeneous and typical of the stand. The actual plot must be the same NPC Class as in the prescription and must be in a patch large enough to hold a 32m^2 plot with no inclusions of other communities.

Step 4: Locate and permanently mark the plot origin. The origin is a point from which two, 32m base-lines must be run at right angles to each other. The origin can be moved or the plot rotated so that the base-lines are reasonably clear of heavy brush, deadfalls, etc. Bury the surveyor's magnet about 2" deep and place the origin flag-pin next to it.

Step 5: Stretch the tape out straight along one base-line (see Figure) and using your compass determine the line's azimuth. Leave the tape in place and put pins in the ground at 32, 16, 8, 4, 2, and 1m from the origin. Using your compass to turn the 90^0 angle, line the tape down the second base-line and install pins at 32, 16, 8, 4, 2, and 1m from the origin.



Step 6: In the example figure working from the "south" baseline, interior corners are "roughed in" by placing two temporary pins due north of the 2, 4, 8, 16, and 32 meter baseline pins. If one were at the 2m baseline pin, then temporary pins are placed at 1 & 2 m to the north; at the 4m baseline pin at 2 & 4m, etc.

Step 7: Working from the "west" baseline, the tape is lined over the temporary pins to the east and then the temporary pins are moved to the correct distance along the tape.

Step 8: The plot is completed by then placing the pin at the northeast corner of the initial 1m^2 plot.

Step 9: At the top of the ECS Species-area Plot worksheet record the basic plot information including: the 5-6 character code for the NPC class/type, your name, the date, GPS coordinates in UTM or Lat/Long, the azimuths of the baselines from the origin, and comments. Useful comments include: purpose of the plot, treatment that will affect the plot, staff present, type of permanent origin marker and corner markers, and anything else that will help with plot re-location.

Species-area Plot Worksheet		Version 1.0, January 2009 John C. Almendinger	**NPC Code:**
Name:			**Date:** / / (mm.dd.yyyy)
Coordinates of Origin			**Azimuths of baselines**
Easting:	**Northing:**		**Baseline 1:** degrees
Lat:	**Long:**		**Baseline 2:** degrees
Comments:			

Step 10: Enter the plant occurrence records, starting in the 1m^2 plot. For each species in the plot record the cumulative area sampled (1) in the small box and then write the species name in the wide box. Record the occurrence of all species, including unknowns, just for this plot. Move to the square 1m^2 plot to the east and record the cumulative area (2) and only plants not encountered in the previous plot. Move to the rectangular 1x2m plot to the north and record the cumulative area (4) and record only plants not encountered in the previous two plots. Continue sampling the plots in order: 8, 16, 32, 64, 128, 256, 512, concluding with 1024.

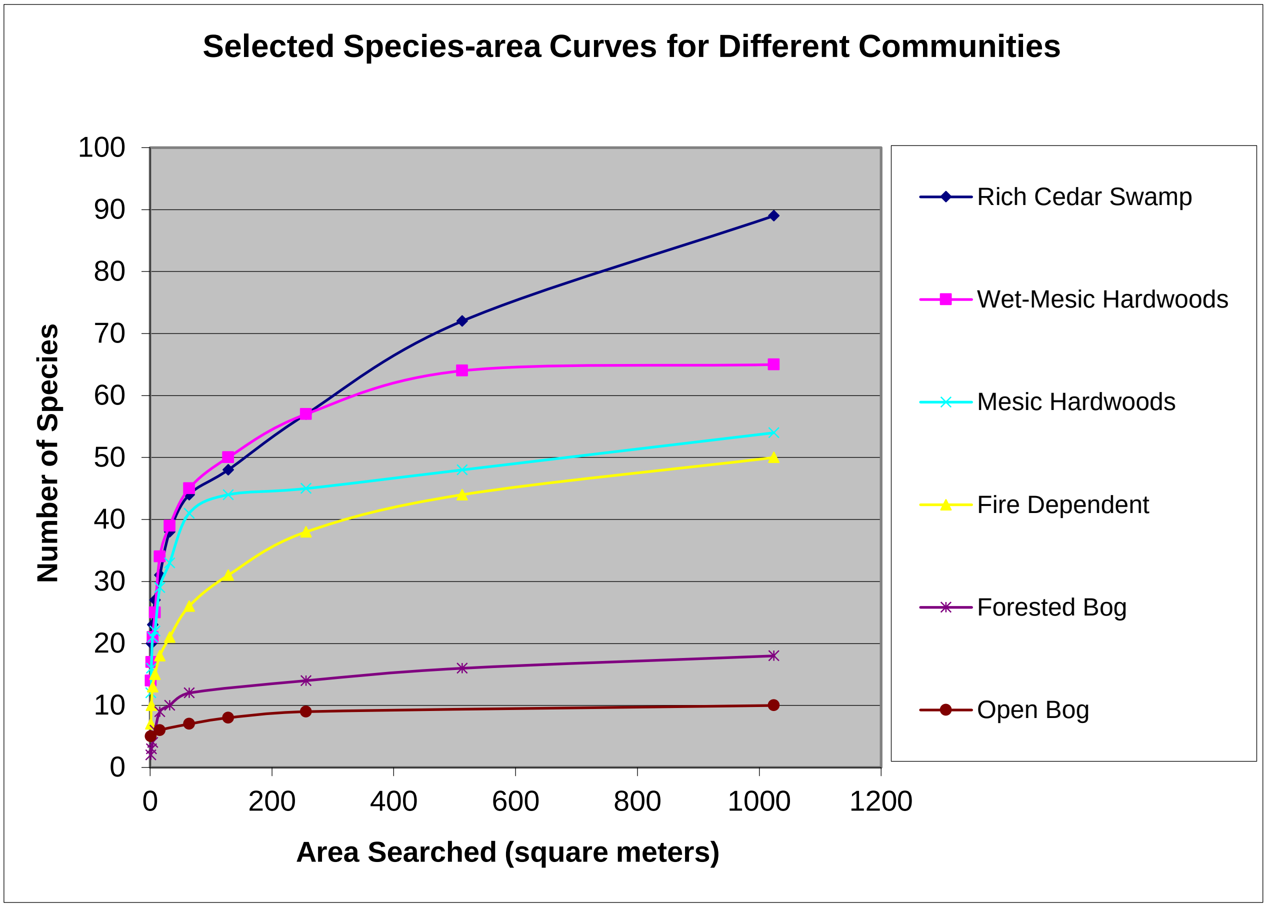
Example	
1	Maianthemum canadense
1	Pteridium aquilinum
1	Unknown #1
2	Oryzopsis asperifolia
2	Gaultheria procumbens
4	Chimaphila umbellata
8	Abies balsamea
:	:
1024	Pinus banksiana

Step 11: In the field, check to be sure that all information has been recorded. If the treatment will leave trees, it is useful to take photographs down the base-lines from the origin. Such photographs are remarkably accurate in re-locating the plot origin.

Step 12: Back at the office, photocopy the field form and file the photocopy where you can find it. Mail the original copy to the address shown on the form for data entry. Send also to that address any unknown plant specimens or photos of unknown plants.

Analysis and Use of Species-area Plot Data

The usual use of species-area plot data is to make graphs, called species-area curves that help us envision plant diversity. These graphs plot the number of species observed on the ordinate by the total area of land searched. They curve because it becomes increasingly difficult to find new species even when a large area is searched. For most regions of the world, the curves level out before botanists lose patience – the limits theoretically reflect the maximum number of available plant niches. In Minnesota, the limits range from about 10 species in open bogs to about 100 species in rich swamp forests (below). Most of our terrestrial forests have limits between 40 and 60 species.



Our **first objective** is achieved by pooling species-area curve plots that belong to the same NPC Class and that have no obvious signs of recent disturbance. The mean number of species is calculated for all cumulative areas sampled to produce a benchmark curve for the “natural” community.

Our **second objective** is met by examining the species-area curve for the site. One estimates the asymptote limit and multiplies that number by the desired level of species conservation for legacy patches. One then uses the curve to see how large a patch must be reserved to protect that many species from the treatment.

Our **third objective** is to document the re-colonization, or recovery of the plot to its pre-treatment state. Species-area plots allow for both a community metric and also provide a summary of what has happened to the individual species. Below is a standard output table for the community interpretation. It is an example of a treatment that had the effect of reducing species diversity at all scales except the very largest 1024m^2 plot. In theory, we would declare a plot to be recovered when a re-sampling yields zero difference. In practice, this will never happen but the values should approach zero. Until there is a corpus of samples for a community and we have calculated variance in the number of species for each plot size, we won't know the level of difference that would indicate recovery.

Area (m2)	Before	After	Difference
1	9	5	-4
2	10	5	-5
4	13	6	-7
8	15	7	-8
16	17	10	-7
32	22	15	-7
64	27	22	-5
128	34	25	-9 max
256	40	31	-9 max
512	47	42	-5
1024	50	54	+4 max

For the species in the plot, there are five possible outcomes of the treatment.

1. Species Apparently Lost Due to Treatment. These are plants present in the pre-treatment plot but not the treatment plot. For re-sampling of permanent plots, this is direct evidence of extirpation. For benchmark comparisons, it suggests species loss in 1024 m^2 patches.

2. Species Conserved at a Coarser Scale. These are plants present in both samplings, but now their distribution seems coarser due to treatment. For re-sampling of permanent plots, this means that the plant has been extirpated from one of the smaller plots. For benchmark comparisons, it suggests species loss at a fine-scale, but not at coarser scales.

3. Species Conserved at the Same Scale. These are plants present in both samplings at the same scale. This suggests that the treatment had no effect on the plant in either re-sampled plots or benchmark comparisons.

4. Species Conserved at a Finer Scale. These are plants present in both samplings, but now their distribution seems finer due to treatment. For re-sampling of permanent plots, this means that the plant has ingressed onto a smaller plot. For benchmark comparisons, it suggests that the plant has expanded its local population due to treatment.

5. Species Appearing Due to Treatment. These are plants appearing after treatment due to seedbank release or ingress. For re-sampling of permanent plots, this is direct evidence of establishment. For benchmark comparisons, it suggests species gain in 1024 m^2 patches.

Our **fourth objective** is to use our knowledge of the species to infer effects of the treatment on the non-living elements of the site. This is mostly art, but there are some calculations and ways of presenting the information that make this interpretation easier.

One thing to do is to calculate the synecological score of the entire 1024m^2 plot before and after treatment. This allows us to guess if the site got warmer or cooler, lighter or darker, richer or poorer, and wetter or drier. Silvicutural treatments are expected and often designed to increase the amount of heat and light reaching the forest floor – thus increases in the synecological scores for these coordinates would signal that the treatment had that effect. Changes in nutrient availability due to treatment are complex and involve lag-times of unknown duration. Silvicultural theory predicts a flush of nutrients that were tied up in slash and the organics of the forest floor – and a “good” prescription results in trees getting those nutrients more so than other plants, in which case we would not detect a shift in synecological scores. More than any other factor though, we expect to see shifts in the moisture coordinate. This is because moisture explains most of the plant distribution at the stand scale and because it mediates or is affected by the other synecological factors. Shifts in the synecological coordinates are a crude measure of ecosystem change, but they will alert us to treatments where we need to monitor impacts with more sophisticated methods.

The **fifth objective** is met by simply keeping track of whether the species on the plot are native or not. Species-area plots are a crude measure of the treatment’s effect on these populations, but they too will alert us to treatments where more sophisticated methods need to be applied to track invasive plant populations.