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Case Studies in Ecological Silviculture

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Contents

Background & Introduction

The MNDNR Division of Forestry manages forests in a way that is heavily biased towards field operations. Administering timber sales and regenerating future commercial forests occupies the most staff time and largest portion of the annual budget. The current management system and administrative structure is incredibly efficient and serves well our industry clients. However in these times, we are reminded by our colleagues in other Divisions, by the process of certification, and by the public who entrust 4.5 million acres of forest land to our care that our clientele is broader than the existing industry and that the ecological services of forests amount to more than traditional forest products.

Under the current management regime the MNDNR separates clients temporally. The average stand rarely attracts forester attention until it is at commercial rotation age and appears on the examination list. Almost always stands this old will have mature commercial timber; almost always stand re-initiation (clear-cutting) is the only viable silvicultural strategy; almost always foresters are done with the stand when regenerating trees are declared “free-to-grow” some 1-5 years after the harvest. From free-to grow to rotation age, some 40-60 years, the “other clients” are free to recreate, observe, and use that stand within the confines of their imagination. Isn’t that good enough? Does it matter that plants, animals, and humans must move over to find a “suitable” forest every rotation? Are we missing silvicultural opportunities by not manipulating young and middle-aged forests? How would we know? Amazingly, with nearly 3,000 annual timber sales, we have never really followed the development of a re-initiated forest from beginning to end. This is why we need long-term case-studies.

Need

There are four good reasons to initiate case-studies:

1. **To learn and teach by example.** Case-study sites are to be places where foresters and other professional land managers can see and experience a variety of management strategies.
2. **To move away from agricultural development of forest sites.** Agricultural development is expensive. It is by nature contrary to managing for biodiversity and stand complexity. We hope to learn through case-studies that more attentive, frequent, and creative management can substitute for agricultural approaches.
3. **To experiment with adaptive forest management.** The crux of adaptive management is monitoring and management flexibility. Clearly frequent monitoring will be more expensive than our usual short-term involvement with any single stand. Is intensive monitoring worth it? Can we avoid expensive treatments, improve yield or quality, or produce a greater variety of products by simply paying greater attention to stand development? Standard case-study monitoring should be efficient and practical should we choose to make it a part of our normal stand inventory.
4. **To take advantage of ECS.** Case studies could involve some non-standard monitoring that is too time-consuming and expensive for everyday use. The ECS maps and NPC classification provide the tool for logical extrapolation and organization of case-studies.

Definition & Purpose

Case studies monitor the effect of silvicultural treatment(s) on forested Native Plant Communities throughout the life of the stand. They are documented and published 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.

Standard Monitoring – ECS Program

Standard monitoring methods are important because it assures the comparability of data between case studies and between re-samplings. These measurements will generate data that needs to be managed and analyzed. The ECS Program is to receive, enter, analyze, and archive all standard monitoring data.

Assessment of regeneration is required when a silvicultural system has been implemented to establish or recruit future crop trees. A pre-treatment measurement of advance regeneration is required, and natural regeneration is to be re-measured in the first and fifth growing seasons. **(see Procedure for Measuring Regeneration, p)**.

Assessment of growth is required when a silvicultural treatment is aimed at release or improved growth of residual trees. Stand growth is measured by BA before treatment, after one growing season, and after 5 or more growing seasons. The growth of individual trees is measured by comparing radial growth before and after treatment. Radial growth measurements can be taken at any time after the treatment, but a minimum of about 5 growing seasons after treatment is probably required for significant results. **(see Procedure for Measuring Growth, p)**

Monitoring plant diversity is required for all case studies. Permanent species-area plots are to be installed and measured before the treatment. These plots are to be re-measured in the first and fifth growing seasons following the treatment. **(see Procedure for Measuring Plant Diversity, p)**

Photo monitoring of the stand to coincide with the ground-monitoring schedule is extremely useful: pre-treatment, first growing-season, and fifth growing-season monitoring. Field observations will aid in photo interpretation. The photos will be taken by the Resource Assessment office. They should be at about 1:5K scale, and stereoscopic. Season of flight, film, and camera format will vary depending upon the NPC Class and silvicultural treatment. The primary purpose is to understand pattern of residual mortality, whether within leave patches or adjacent stands. Field measurements will document the magnitude of mortality, but only photos will show if the pattern is related to poor sale design or edge-effects. In addition the photos are a powerful communication tool for illustrating the pattern and amount of canopy removal associated with the various silvicultural systems. **(see Procedure for Photo Monitoring, p)**

Special Monitoring – ECS, Forest Health, Invasive Plant Programs, etc.

The standard monitoring is aimed at the most common reasons to treat a stand – regeneration and growth of trees, and conservation of the groundlayer vegetation. There are other reasons for silvicultural treatment. For example, treatments might be aimed at mitigating disease or diminishing populations of insects or invasive plants. Alternatively, one might want to measure in greater detail the effect of a treatment on the site: soil compaction, groundwater levels, stream flow, or nutrient cycling.

The ECS Program will help facilitate special monitoring, but all measurements and data management are the responsibility of the group or person requesting such monitoring. The ECS Program will archive such data so that a report on all monitoring activity on a site can be assembled and summarized.

Retrospective Measurement & Benchmarks – ECS Program

Retrospective measurement and the establishment of community benchmarks are <u>not</u> part of the case-study project. Their mention is important because case-study monitoring measurements can be applied to any stand with a reasonably good record of silvicultural treatment. For example, a 10-year old case-study might help us understand how a 20-year old stand arrived at its current condition as measured retrospectively. On the other hand, a retrospective study of the 20-year old stand might alert us to features of a 10-year old case-study stand that need measurement but are not part of the standard case-study methodology.

Benchmark studies have as a goal the definition of a “good,” “healthy,” “typical,” etc. native forest. All case-study pre-treatment measurements can contribute to the definition of benchmark conditions for a NPC. Conversely, benchmarks can substitute for pre-treatment measurement in retrospective studies. Benchmarks are important because most criticism of forest management practices comes from a perception as to how different treated sites are from what is “natural.” Without actual pre-treatment measurement or benchmarks, neither the critic nor the forester knows what they are talking about when debate arises.

The databases developed about our case-study program and those to hold retrospective and benchmark measurement are one-in-the-same. Retrospective studies have the huge advantage of yielding results within our lifetime and will for that reason guide changes in management in the near future. We are in a race to define benchmark conditions before it is impossible to untangle the effects of management from global factors that affect forests (climate, invasives, etc.). However, all ecologist tricks to substitute spatial pattern for time (including benchmarks) are fraught with assumption. There are precious few long-term studies to guide future foresters, and formal case-studies are an important start.

Procedure for Measuring Regeneration – Fixed-radius Plots

Objectives
There are three main objectives that fixed-radius plots can address for each species in the stand:

1. **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 of the site and compare stocking results among different treatments.
2. **Understand how diameter relates to post-treatment survival and recovery.** For each species, comparing survival by diameter class will help to understand how predictive diameter is of surviving or responding to treatment.
3. **Understand the effect of other plants on tree establishment.** Plots for the smallest trees will have in addition to the tree counts, an accounting of the co-occurring plants. The purpose is to understand if certain plants have a positive, negative, or benign relationship to tree seedling survival or establishment.

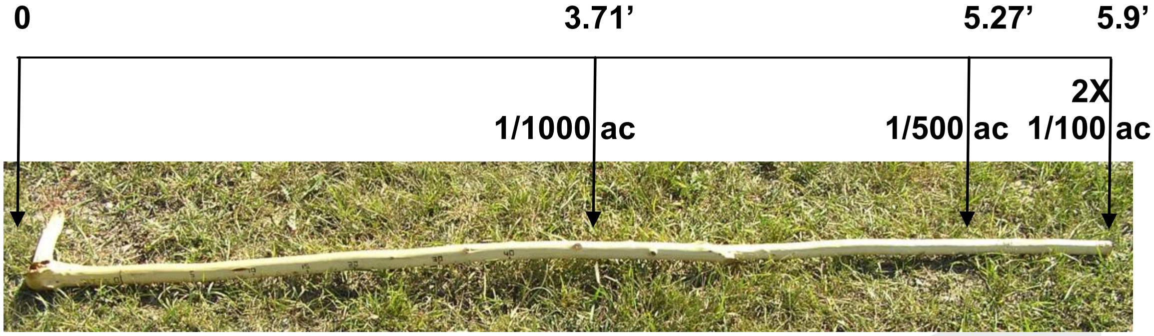
Field Procedure for Installing Regeneration/BA Plots

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, and a BA prism.

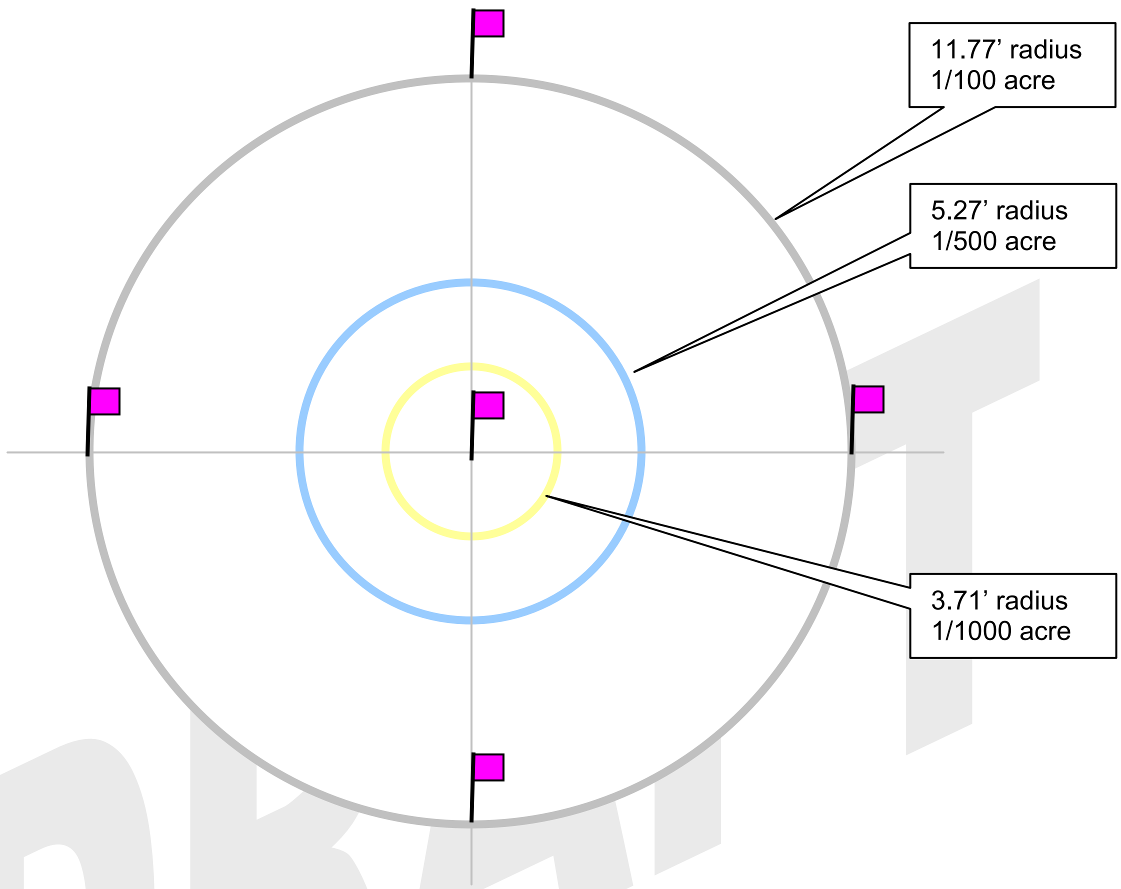
Typical Layout Stick

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.



This layout stick is an aspen with its sucker attached to form an "L." The 3.71 and 5.27 foot marks are the radii of a 1/1000 and 1/500 acre plot respectively. Two full stick lengths are yields the 11.8' radius of a 1/100 acre plot. The 1, 3, and 5 inch marks on the sucker (below) help determine sapling diameters in the 0-1, 1-3, and 3-5 inch classes. Biltmore and hypsometer scales are also burned onto this particular stick.

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° angle.



Typical Layout of a Regeneration Plot

Step 4: At the top of the ECS Regeneration Plot worksheet 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 sampling transect, starting azimuth, target number of plots per acre, and the factor and units of the BA prism that you will be using (if measuring BA). The starting coordinates are very important as the <u>coordinates, not the site name, are what ties the worksheet to the stand</u>; also this allows one to get started re-sampling the stand if it is desirable to approximate the same pattern and density of plots for re-measurements.

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		Version 1.0, 2009 John C. Almendinger	NPC Code:	
			Site Name:	
Name:			Date: / /	(mm,dd,yyyy)
Coordinates of Origin (where transect starts)			Azimuth of transect grid:	degrees
Easting:	Northing:		Sampling density:	plots acre
Lat:	Long:		Prism Factor/units for BA:	X, ft^2 / m^2
Comments:				

Step 5: Start by recording whether the plot is within a treated/harvested area (T) or if the plot is in a leave or legacy patch (L). For the pre-treatment sampling, every plot is potential legacy (L).

Start tallying the stem counts of tree regeneration on the 1/1,000 acre plot, using the layout stick to swing the 3.71' radius of the plot. For each tree under 1" diameter, record the plot number, the species, the tally and stem count (tally sum) in a single row on the field form (example below: 1 sugar maple (tally marks) 64; 1 basswood (tally marks) 6). The quarter flag-pins on the 1/100 acre plot can be used to start and keep track of how many quarters have been examined as the tally accumulates. For very abundant species representative quarter or half plots can be used to estimate the stem count, but you must enter the multiplication factor in the tally column (e.g. sugar maple (tally marks) X 4).

After the trees <1" diameter have been recorded on the 1/1000 acre plot, repeat the process for all non-tree plants (peduncled sedge, bracken, Clayton's sweet cicely, and fly honeysuckle below). Do NOT count their stems, but rather <u>indicate their presence in the entire plot with a check mark</u>. <u>Non-tree species are recorded only on the 1/1000 acre plot</u>.

Sample Table on next page ⇓

Sample Table

T/L	Plot #	Species	<1" 1/1000 acre		1-3" 1/500 acre		3-5" 1/100 acre		Prism
			Tally	Total	Tally	Total	Tally	Total	Count
Example									
L	1	Sugar maple	卌 卌 卌 | X4	64	卌 卌	10	卌	5	8
	1	Basswood	卌 |	6	||	2	|	1	3
	1	Ironwood	|||| 卌	4					
	1	Peduncled sedge		✓					
	1	Bracken		✓					
	1	Clayton's sweet cicely		✓					
	1	Fly honeysuckle		✓					
	1	Red oak			|	1	||	2	1
	1	Quaking aspen			||	2	|	1	2
	1	White Pine					|	1	1
T	2	Sugar maple	卌 卌 卌 卌 || X4	88	卌 ||	7	|||	3	
numbers are stem counts; presence checks for non-trees in 1/1000 plot only									

Step 6: Enter the 1-3" diameter tree occurrence records in the 1/500 acre plot. Use the layout stick to swing the 5.27' radius. Start by recording the stem counts of species previously encountered on the 1/1000 acre plot (example above: sugar maple and basswood). For new species record the plot number, species, tally, and stem count (example above: 1 red oak (tally mark) 1 and 1 quaking aspen (tally marks) 2.

Step 7: Enter the 3-5" diameter tree occurrence records in the 1/100 acre plot in parallel fashion as described for the 1/500 acre plot. For this plot you must visually estimate the plot edge using the flags as a guide. Trees close to the edge can be checked to see if they are within two layout sticks of the plot center.

Step 8 optional: If stand-growth measurements are planned for the site, <u>it makes perfect sense to link those growth plots to the regeneration plots</u>. This field form allows for entry of counts of prism trees to estimate basal area of the stand or treatment unit. The justification for measuring stand growth as BA and application is covered in the Procedure for Monitoring Growth section.

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. Add any new species to the bottom of the data block for the plot (white pine above). Be sure that the prism factor and units has been recorded on the top of the starting worksheet. Complete the block of records for the plot by drawing a thick line or by skipping a line at the bottom of the block . This helps to separate the plot records and reduces errors in entering plot records.

Step 9: After a block of rows had been entered for a plot, draw a heavy line or skip a row to separate that plot from the next. This practice reduces data-entry errors. Consider the Step 10 option, pick up the wire flag-pins, and move to the next plot.

Step 10 optional: If the treatment will leave 3-5" trees one can paint or flag the trees in the 1/100 acre plot if it is desirable to re-locate 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 fairly accurate re-establishment of plot centers.

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

Regeneration/BA Plot Worksheet continuation ...			**Site Name:** Date:					**Page:**	
T/L	**Plot #**	**Species**	**< 1" 1/1000 acre**		**1-3" 1/500 acre**		**3-5" 1/100 acre**		**Prism**
			Tally	**Total**	**Tally**	**Total**	**Tally**	**Total**	**Count**

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

Step 13: 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 starting worksheet for data entry. Send also to that address any unknown plant specimens or photos of unknown plants.

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 stocking 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 x 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 x. Density (n, trees per acre) and proportional 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. Proportional change 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. Proportional (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 recovery, is best illustrated in a table (Table y. 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 y. 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 $1/1{,}000^{th}$ 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 $\mathbf{X^2}$ 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

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

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

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

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

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

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 where the trace holds the trivial, perfect correlation of a plant with itself.

Table Z-1. 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 Z-2).

Table Z-2. 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.

Procedure for Monitoring Growth – VR Plots, Stem Increment

Objectives

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

1. **Measure stand growth as a response to thinning.** Measuring stand basal area (BA) before treatment, after 1 growing season, and after four growing seasons allow 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.
2. **Measure mean growth of different species as a general response to the thinning regime.** The annual increment of individual tree growth is 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.
3. **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.
4. **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 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 x. 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 is 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 was obvious that lots of trees on the paths were damaged by skidding, then we might want to divide the trail edge treatment into intact tree and damaged tree 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.

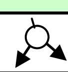
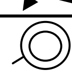
After constructing the matrix, one should pick evenly distributed spots where one should be able to find enough trees to core and fill the sampling matrix.

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	

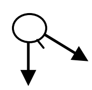
TC is the "Treatment Condition" as defined in the Treatment Legend. Use the numbers 1-4 as defined. If more treatment classes are needed, document these and their numbers in the comments section.

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 an 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.

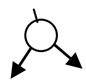
CR is the tree's crown ratio. Visually estimate the proportion of living crown to total tree height to the nearest 10% and enter that number.

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.

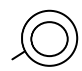
Rls is a graphic that shows the side and extent of crown release and where the core was taken.



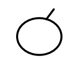
Release between
~110-180°
Core on SE side



Release between
~215-115°
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.

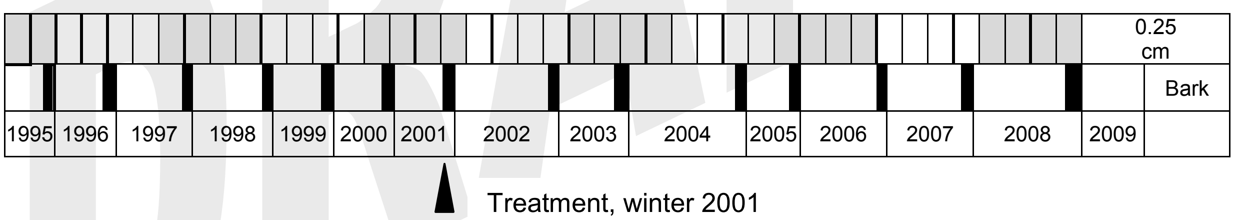
Tally Matrix	Treatment			
Species	**1**	**2**	**3**	**4**
Balsam fir	~~IIII~~	~~IIII~~	~~IIII~~	
Quaking aspen	~~IIII~~	~~IIII~~	~~IIII~~	
White spruce	~~IIII~~	~~IIII~~	~~IIII~~	

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

`**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							

Analysis and Use of Radial-growth Data

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 x.), 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 x. 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 *a priori* 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 x. (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 x. 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 not 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 x.) 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 x).

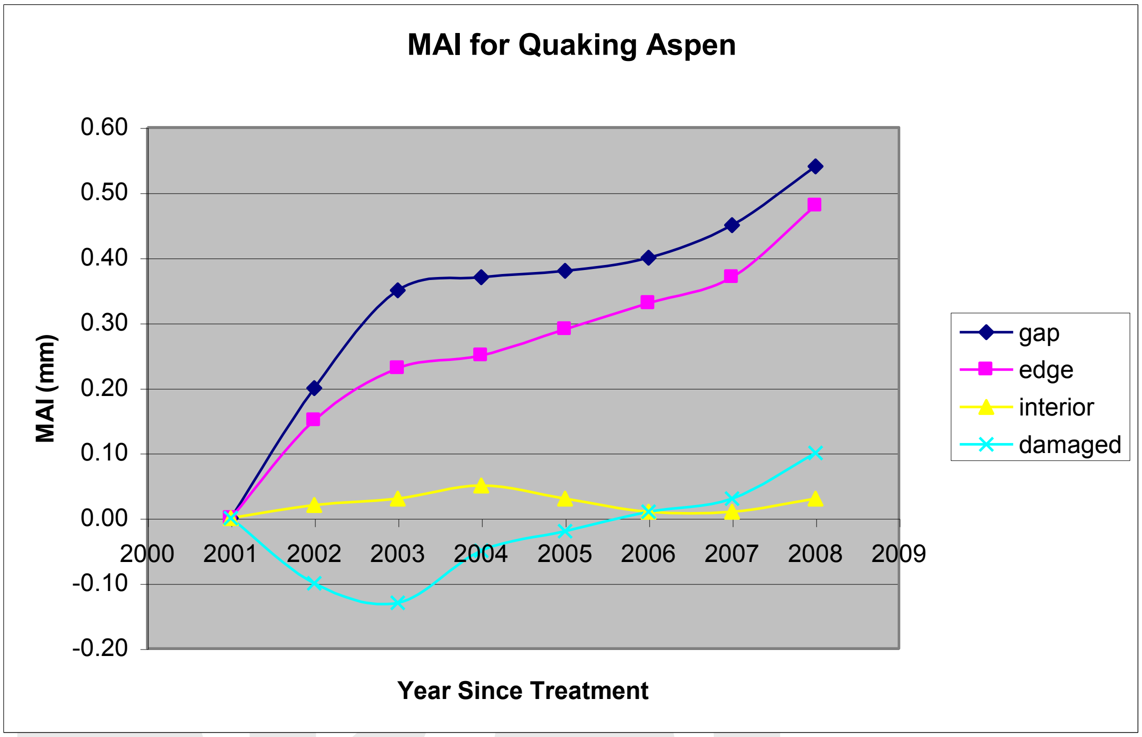


Figure x. Departure of annual increment from mean pre-treatment increment in 2001 for quaking aspen.

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 x. 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 x. 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 – Species-area Plots

Objectives

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

1. **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).
2. **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.
3. **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.
4. **Infer the effect of the treatment on the forest ecosystem**. While it is possible to instrument and 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.
5. **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.

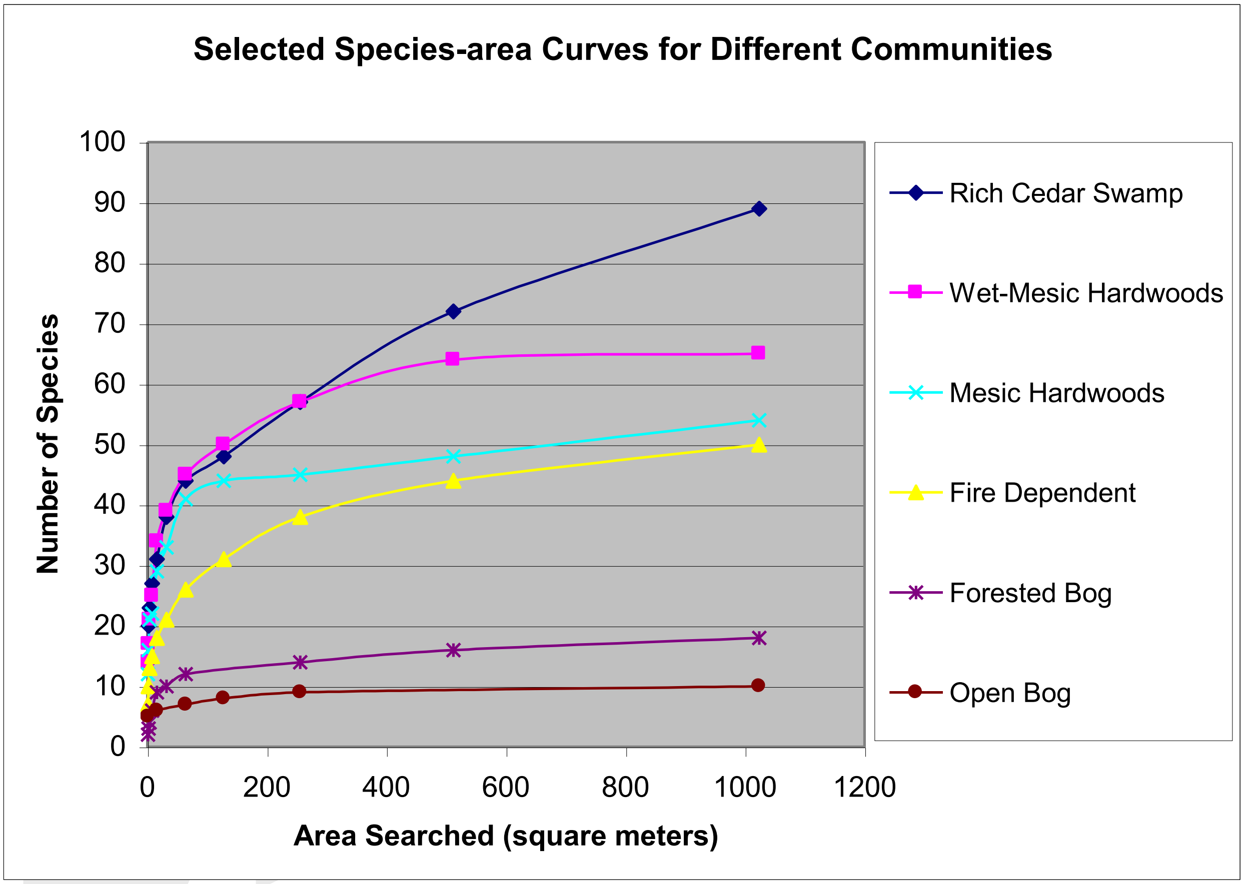
Example	
1	Maianthemum canadense
1	Pteridium aquilinum
1	Unknown #1
2	Oryzopsis asperifolia
2	Gaultheria procumbens
4	Chimaphila umbellata
8	Abies balsamea
:	:
1024	Pinus banksiana

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 reach asymptotic limits 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 (Figure). 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.

Procedure for Photo Monitoring

Objectives
There are two main objectives that photo monitoring can address:

1. **Define the pattern of residual tree mortality following a silvicultural treatment.** Field measurements will document the magnitude of mortality, but only photos will show if the pattern is related to poor sale design or edge-effects.
2. **Communication of the pattern and degree of canopy removal for the various silvicultural systems.** Better than writing, such photos will provide field foresters with a better understanding of what sites should look like after treatment for silvicultural systems that involve partial harvest. Also, the photos can be rectified and modified to show the distribution of plots that need to be found and re-sampled.

Procedure for Photo Monitoring

Step 1. Using air photos and available GIS software, create the polygon that encompasses the treatment area.

Step 2. Send the treatment polygon and a short description of the project to the Resource Assessment Office for evaluation and advise. You must work with the RA staff to define:

- Scale (normally ~ 1:5,000 to 1:8,000)
- Stereoscopic coverage
- Season & schedule (1st and 5th growing-seasons)
- Film & camera format
- Photo-rectification (rectifying to 1st growing season photo)

Step 3. Inspect the photos to make sure that: 1) individual trees and their crowns are visible, 2) that you have full stereoscopic coverage of the treatment polygon, and 3) that the 5th growing season photos have been rectified to the 1st growing season photos and not a standard base.

Step 4. On the 1st growing season photo set, mark on every other photo the location of: important edges of reserve areas and adjacent stands, skid trails, landings, etc. The purpose is to define and illustrate the actual treatment in GIS layers. These features must be digitized using the 1st growing-season photos as a background.

Step 5. Compare the 5th growing season photos with the 1st growing-season photos using the treatment covers as a guide. Create a point cover of individual trees that seem to have died, including azimuth of downed trees (base to tip).

Use of Monitoring Photos and Covers

For the most part, the photo set is a supporting activity for describing and communicating the results of the other monitoring efforts (**Objective 2**).

The only new information is the point cover of standing dead or downed trees since the 1st growing-season photo was taken. For the most part, the interpretation is visual – is the distribution of dead trees correlated with the actual design of the treatment.

The only possible analysis would be to see if the azimuth of tree-fall is correlated with the treatment design. This is best done visually by plotting azimuth arrow symbols where trees have gone down.

Standard Documentation

Documentation needs be standardized so that the results of different treatments can be compared among stands with similar pre-treatment conditions. The standard documents comprise the information routinely collected or prepared for MNDNR timber sales, thus allowing a forester to match any timber sale with a case study if one exists.

NPC Class of the site and forest growth-stage are essential information because the case studies and silvicultural information are organized by the NPC classification and stand growth-stage. An ECS Site Classification Worksheet must be completed for all case studies **(ECS Site Classification Worksheet, V1.3)**

Timber appraisal and yield are important measurements because timber production is the primary impetus for managing forests and logging remains the foremost management tool. Thoughtful management strategies tend to balance yield, legacy, site integrity, and cost. These elements are the currency for comparing the sustainability and practicality of "new forestry" strategies with traditional ones. Also, the appraisal can help us match sites more closely than the combination of just NPC Class and growth-stage. A Timber Appraisal Report is required for all case studies involving harvesting as part of the treatment **(Timber Appraisal Report, NA-02136-06).**

The prescription is an important element of a case study because it places the treatment in context of a management strategy and it explicitly defines: the treatment objective, the desired future condition, and the long-range plan for the stand. These things are essential considerations in evaluating the success or failure of the treatment. The Stand Silviculture Prescription Worksheet is required for all case studies **(Stand Silvicultural Prescription Worksheet V1)**.

A GIS cover of the treatment area and any point samples within the treatment area is required for all case studies. This is important so that permanent plots can be re-located and so that years from now the treatment can be evaluated beyond our 5-year assessment **(Standard ESRI polygon or point shape files)**.

Management of the standard documents is the responsibility of the ECS Program. The management procedure is to:

1. Submit any paper copies to the ECS Program so that they can be scanned for archival purposes.
2. Submit any electronic copies to the ECS Program so that they can be archived.
3. The archived documents will reside on the Resource Assessment server in a folder with access limited to the ECS Program and others involved with case studies.

Publishing & Posting Case Studies

The ECS Program is responsible for publishing and posting case studies to the ECS Web site **(see example)**. The Program will develop a standard template and style for writing case-studies. One purpose of the template is to create parallel construction from one study to the next so that an interested forester can quickly find comparable information. Another purpose is to force discussion about a core set of considerations as follows:

Desired future condition should be described in detail for both composition and structure. Here, "detail" means to at least identify the future ECS growth-stage and composition. The landscape contribution of the stand to plan goals can be mentioned here if known **(source: Stand Silvicultural Prescription Worksheet V1)**.

Prescription for moving the stand to DFC should be stated in full. This places the treatment in context of a longer-term plan for the stand **(source: Stand Silvicultural Prescription Worksheet V1)**.

Objective of the treatment should be described in enough detail so that the results can be described as successful or not. The contribution of the treatment towards re-initiating, transitioning, or maintaining the stand – or the contribution towards restoring a missing element should be stated using these terms. The likely effect of the treatment on local populations of all trees – increase, decrease, or no effect – should be stated **(source: Stand Silvicultural Prescription Worksheet V1)**.

Purpose of forest legacy should be linked to re-colonization and DFC. That is one should explain the likely contribution of seedbanks, rootstocks, leave trees, reserve patches, or adjacent stands to the forest that will ultimately occupy harvested areas. Given the actual or planned condition of harvested areas, why should it be receptive to re-colonization, survival of planted stock, or recruitment of advance regeneration? Which species are favored or not under such light and seedbed conditions? **(source: ECS Silvicultural Interpretations)**

Sale design or treatment administration must be described in enough detail so that it can be critiqued with regard to conserving the ecological integrity of the site. Discussion should address the treatment's effect on: soil resources, hydrology, riparian communities, insect and disease concerns, and invasion of exotic plants. **(Timber Appraisal Report, NA-02136-06)**

Summary of the forester's general sense of how well the treatment worked. A brief chronological recount of what happened should follow the opinion of success or failure. The summary should conclude with commentary about what should be done differently if the treatment were to be repeated.

Example Schedule for Documenting and Monitoring

It takes about 7-12 years to produce a case study worth publishing or posting to the ECS Web site. One constraining factor is the fact that MNDNR administration of timber sales can take up to 5 years for completion. Another constraining factor is the amount of time it takes to bring a cohort of seedlings to reach the "free-to-grow" stage or the time it takes to believe that released trees are truly showing improved growth. The table below shows roughly the sequence of events required for a standard case study, and it could serve as a template for developing a case-study plan.

Event	When	Responsible Party
ECS Worksheet Completed	Summer – Year 1	Area staff
Appraisal	Fall or winter – Year 1	Area staff
Prescription	Winter or spring – Year 1-2	Area staff
GIS cover and plot location	Winter or spring – Year 1-2	Area staff & ECS Program
Install regeneration/BA plots	Summer – Year 2	ECS Program
Install species-area plots	Summer – Year 2	ECS Program
Enter benchmark data	Winter – Year 2	ECS Program
Treatment (1-5 years after completion of the above sampling)		
Update Appraisal for yield and administrative comments	After treatment if harvested	Area staff
Re-measure regeneration/BA plots	Late summer – Year 3	ECS Program
Re-measure species-area plots	Late summer – Year 3	ECS Program
Fly 1st growing-season photos	Late summer – Year 3	Resource Assessment
Enter monitoring data	Winter – Year 3	ECS Program
Update/modify plot locations	Winter – Year 3	ECS Program
Write draft case-study	Winter – Year 3	ECS Program
Sampling Hiatus		
Re-measure regeneration/BA plots	Summer – Year 7	ECS Program
Re-measure species-area plots	Summer – Year 7	ECS Program
Fly 5st growing-season photos	Late summer – Year 7	Resource Assessment
Radial-growth measurements	Fall or winter – Year 7	ECS Program
Enter monitoring data	Winter – Year 7	ECS Program
Complete & post case-study	Winter – Year 7	ECS Program

Appendix A – Priority Case Studies 2009 – ?

The ECS Program will meet, after consultation with the Silviculture Program to develop a matrix of NPC Classes by silvicultural treatments that are consistent with the natural dynamics of the Class. That is for each NPC we will determine treatments that mimic natural processes. By looking at that matrix, we will decide which treatments require confirmation because they are commonly applied or experimental treatments that should be applied after testing.

This list will be prioritized submitted to Alan Jones for approval and case-studies will be implemented based upon his advise.

Appendix B – Metadata

Appendix C – Standard Forms

Junk notes needed for reference and future revisions

Clearer definition, purpose, objectives and direction (re: target communities, and laundry list of treatments). I must work with the region silviculturists to determine the directions) Priority by: problems, traditional, new ideas from ECS.

Plan for data management, writing, communication, and where all this shit resides (SRM). The data must be managed by the ECS program because SRM is useless for analysis.

Much greater detail in information collected than what we usually do. Add: survival monitoring year 1 (Silv Program and I&D)

Work load is on ECS program and foresters are out.
Work load includes cumulative database management.

Wants a procedures manual. Delegate responsibility.

Schedule.

Ideas that are scratched for now

Procedure for Monitoring Seedling Survival – Population Study

Objectives
There are two main objectives that a population study can address for each species planted:

1. **Survival rate of the planted population.** Marking and counting a subpopulation of planted seedlings will allow us to estimate the proportion that has survived.
2. **What agent(s) is likely responsible for seedling mortality**. Monthly monitoring and collection of dead seedlings could provide an understanding of how trees died during their first growing season.

Background and Introduction
Forests are home to a great many organisms. If we were to seriously consider and monitor the impacts of forest management on their populations – even within the confines of a single stand – there would be thousands of species to monitor in the average Minnesota forest. We care also about how these organisms interact as a local society, the forest community. Manipulating competitive interactions is

at the heart of many management practices, while interactions of any mutual benefit are usually ignored. Foresters speak of productivity, but the currency of wood production – water, nutrients, heat, and light – and the rate at which their regimes drive the carbon economy is rarely a field consideration. Populations, communities, and ecosystem regimes are worthy of study and monitoring with regard to forest management practices. The overwhelming number of possible things to monitor requires that we carefully choose what we can realistically follow in a case study.