

GUIDELINES FOR MONITORING ASSISTED NATURAL REGENERATION

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1 - AIMS AND RATIONAL

The overall aim of FAO Project TCP/RAS/3307, “Applying natural regeneration for restoring forest ecosystem services in Southeast Asia” is to determine to what extent the application of assisted natural regeneration (ANR) can restore forest biodiversity, ecological functions (particularly watershed functions) and carbon sequestration. The concept of ANR is to be adapted from the Philippines model and tested in deforested landscapes in Thailand, Lao PDR, Cambodia and Indonesia. The purpose of these notes is to suggest guidelines for simplified monitoring procedures, which can be applied in each of these countries, by each in-country project implementing organization along with local communities, to determine the effects of 1 year of ANR treatments on forest biodiversity, ecological functions and carbon sequestration. Since it is unlikely that ANR actions will have a large effect on these parameters, within the duration of a 1-year project, the procedures, outlined below, can be used to establish a baseline against which future changes can be measured.

2 - CONTROL AND TREATMENT SITES

Hypothesis: ANR treatments will accelerate recovery of vegetation, watershed functions and carbon sequestration *faster than (non-assisted) natural regeneration.*

To compare assisted with *non-assisted* natural regeneration, each ANR study site should be paired with a “control” site nearby, where no ANR treatments will be applied (including fire prevention). The same sampling effort should be expended at both the ANR sites and the control sites and the measurements made in both should also be identical. Control sites should be close and as similar as possible to the ANR sites, in terms of original vegetation, elevation, slope, aspect, etc. Control sites should be located outside the firebreaks around ANR sites. Control sites may be smaller than ANR treatment sites, provided they are large enough to contain the required number of sample points. Ideally, there should be several pairs of ANR and control sites to achieve a degree of replication, but this is unlikely to be possible within the confines of the current project.

Delineate the boundaries of both control and ANR sites with wrought iron metal poles, placed every 100 m. Wrap coloured sticky tape around the tops of the poles and write an identification number on each pole with an indelible pen. Record the GPS location of each pole and take a photograph looking towards the centre of the study site from each pole, as described in Box 1. Record site details on Data Sheet 1.

	Date:				Recorder:			
	ANR				CONTROL			
Name								
Location (Province District etc.)								
Elevation range								
Average slope								
Average aspect								
FACTORS AFFECTING REGENERATION								
Fire History								
Livestock usage								
Erosion/landslides								
BOUNDARY POLES	POLE ID #	GPS	PHOTO FILE I.D.	PHOTO DIRECTION (DEGREES)	POLE ID #	GPS	PHOTO FILE I.D.	PHOTO DIRECTION (DEGREES)

Data
- Site

Etc. (add lines as needed)								
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Sheet 1

Information

3 – SAMPLING

Circular sample units (SU's) 10 m in diameter have become the international standard for monitoring vegetation recovery as a result of restoration activities². Position SU's evenly across both the control and ANR sites. If the ANR site is patchy, with grass/herb dominated patches intermixed with patches of natural forest regeneration, position SU's to be representative of the grass/herb-dominated patches, where ANR weeding or fertilizer treatments will be applied (random sampling is inefficient in such conditions). The same sample points, established during the rapid site assessment (described in the "Field Manual on Assisted Natural Regeneration"), can also be used for monitoring. A minimum of 10 SU's should be positioned across the ANR site and 10 more across the control site. Construct species/area curves as described in Section 5. If such curves show no signs of leveling off, add more SU's to the survey until the number of new species discovered in each sample unit falls below 10% of the total. Use a wrought iron pole (which will survive fire) to mark the centre of each circular SU and a 5-m-long piece of string (tied to the centre pole) to delineate the SU circumference. Use coloured tape and an indelible pen to apply an identification number to each pole. Record the GPS location of each pole and take four photographs following the instructions in Box 1. Then record additional information on Data Sheet 2.

Box 1 – Photo monitoring procedures

Take photos of the vegetation at all boundary and SU centre poles. At boundary poles, take photos looking towards the centre of the study site. At sample-unit poles, take 4 photos, looking out from the pole roughly N, W, S and E (in that order). Take photos at other locations, which give the best possible view of the whole study site as needed, but place a numbered metal pole at every photo monitoring point, for future reference. Set the camera to the widest possible zoom setting and the highest resolution. Frame each picture to include the top of the pole (showing the pole i.d. number) in the lower right-hand corner. Use a compass to record the direction of the photo. Keeping the top of the pole in the lower right-hand corner of the picture, gradually tilt the camera down to minimized the amount of sky in the shot, so the horizon should be near the top edge of the picture. Repeat photo-monitoring in the mid dry and wet seasons and at annual intervals. Use the same camera with the same zoom and resolution settings for all photos. Transfer photos to a computer as soon as possible and rename the files as follows:

pole reference number_date (yyymmdd)
e.g. B08E_120315 (boundary pole 8, facing east, taken on 15th March 2012).



² Special issue of Forest Ecology and Management 1997 (Vol. 99 Nos. 1-2).

Data Sheet 2 – Sample Unit Details

DATE:	RECORDER:	Sample Unit I.D. #:
STUDY SITE:		ANR or Control:
Slope:	Aspect:	Elevation:
GPS:	N	E
Signs of Fire:		
Signs of livestock impact:		
Signs of erosion:		
Any other distinguishing features:		
Photos	Compass direction (degrees)	Photo File I.D. #
N		
E		
S		
W		

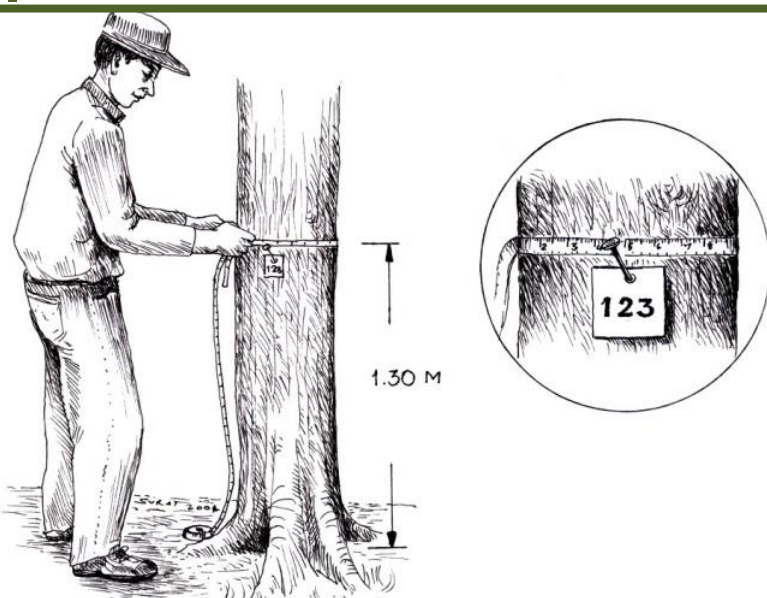
Box 2 - Labeling regenerants

Since regenerants vary in size from small tree saplings to large trees and stumps, a variety of different labels is needed.

For seedlings and saplings use soft aluminium strips, used to bind electrical cables, available from builders' supply stores. They can easily be formed into rings around tree stems. Use metal number punchers or a sharp nail to engrave an identification number on each label and bend them into a ring around the stem, above the lowest branch (if present) to prevent labels from becoming buried.



For larger trees and stumps, use square labels made from drinks cans. Cut off the top and bottom of the cans and slice up the length of the can to open out the metal foil sheet. Cut the sheet horizontally into 2-3 strips and then vertically to make squares. Place the labels on a pad of paper or rubber mat and then use a tough ball-point pen or nail to press identification numbers into these soft metal foil squares (on the inside can surface). On trees of girth 5 cm or more, nail labels to the trunk so that the upper edge of the label is at exactly 1.3 m above the ground, where girth at breast height (GBH) will be measured.



Use 5 cm long, galvanized nails, with flat heads. Hammer only about 1/3 of the nail length into the trunk to allow plenty of room for tree growth.

4 – FIELD MEASUREMENTS

4.1 - Vegetation Diversity

4.1.1 - Woody vegetation

Hypotheses: i) the number of individuals and species of trees, taller than 50 cm, will increase more in the ANR plot(s) than in the control plot(s) over 1 year and ii) weeding (and other treatments) will increase the survival and relative growth rates of trees taller than 50 cm in the ANR plot(s) compared with the control plot(s) over 1 year.

Equipment: metal labels, permanent marker or metal stylus, wire, nails, tape measures (1.5 m), Vernier calipers, Data Sheet #3, pencil, clip board, tree height measuring poles.

Within each SU, label every tree sapling taller than 50 cm and every live tree stump and then use Data Sheet 3 to record i) the label number, ii) the species name (both local name and scientific name), iii) height, iv) for small saplings, root collar diameter (RCD mm) or for larger trees (if girth at breast height (GBH) is more than 5 cm), record the GBH (cm), v) health score, vi) crown width and vii) for tree stumps, the number of coppicing stems. Ask local people for the name of each tree in the vernacular. Work with a botanist to obtain scientific names on-site, or collect specimens for identification at a herbarium later.

Use tape measures to measure the heights of small saplings (taller than 50 cm) (e.g. 1.5 m tape measures mounted on rigid PVC poles). Measure the tree height, from the root collar to the highest meristem (shoot tip). For taller trees, telescopic measuring poles can be used to measure trees up to 10 m tall. These poles are commercially available but can be home-made.



height of small
larger trees.



For small trees, measure RCD at the widest point with Vernier calipers (Box 3). Once a tree has grown tall enough to develop a GBH of 5 cm or larger, measure both the RCD and the GBH (1.3 m from the ground), the first time and only GBH thereafter.

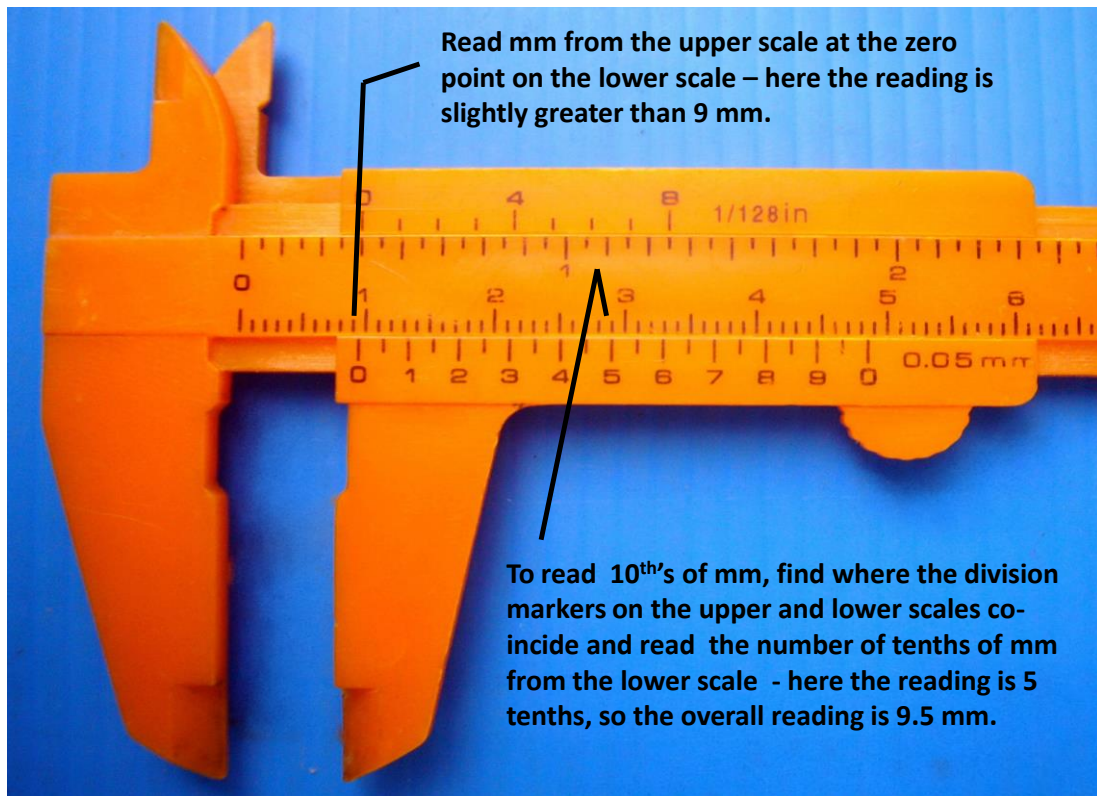
Assign a simple health score (0-3) to each tree and record descriptive notes about any particular health problems observed. Score zero if the tree appears to be dead. For deciduous tree species, don't confuse a tree with no leaves in a dry season with a dead one. Do not stop monitoring trees just because they score zero on one occasion. Many trees, which appear dead above ground, may still have living roots, from which they may subsequently re-sprout new shoots. Score 1 if a tree is in poor condition (few leaves, most leaves discoloured, severe insect damage etc.). Score 2 for trees showing some signs of damage but retaining some healthy foliage. Score 3 for trees in perfect or nearly perfect health.

Measure the width of the tree crown (cm) at the widest part with a tape measure. Any tree seedlings or saplings shorter than 50 cm can be considered as part of the ground flora and need not be individually measured.



Box 3 – Using Vernier Calipers

Vernier scale calipers are available from most stationary stores. At the zero mark on the lower sliding scale, read number of millimetres diameter from the upper scale. For the decimal point, look for the point at which the division marks on the lower scale are exactly aligned with the division marks on the upper scale. Then, read the decimal point off the lower scale. For example, the Vernier scale here reads 9.5 mm. Because RCD is a small value, it must be measured with high accuracy. For best results, measure RCD twice by turning the calipers at right angles and then use the average reading.



SAMPLE UNIT ID #:		RECORDER:			ANR OR CONTROL		DATE:	
Within 5 m radius circle								
Label	Tree Species	Height (cm)	RCD (mm)	GBH (cm) if >5 cm	Health Score 0-3	Crown Width (cm)	No. Coppicing Shoots (for tree stumps)	Notes
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							
	Local ----- Sci.							

Sci.							
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Data Sheet 3 – Trees

4.1.2 - Ground Flora

Hypotheses: i) as ANR encourages tree growth, increasing tree crown cover will shade out grasses and other light-loving herbaceous weeds more rapidly than in the control plot(s) and ii) diversity of the ground flora should increase more rapidly in the ANR plots as dominance of grasses is reduced in favour of a greater variety of non-dominant, shade tolerant species.

Within the same SU's used for the trees, first estimate gross structural composition, including coverage of the SU by rock, bare soil, leaf litter, all grasses, all other herbs, shrubs and tree crown cover. Use the Braun-Blanquet Score to categorize the estimated cover.

Braun-Blanquet Score	
Sparsely or very sparsely present, cover very small	0.1
Plentiful, but of small cover value	1
Very numerous or covering at least 5% of area	2
Any number of individuals covering 1/4 to 1/2 of area	3
Any number of individuals covering 1/2 to 3/4 of the area	4
Covering more than 3/4 of the area	5

Next use the same scoring system to estimate the cover of each herbaceous species and the presence of any small tree seedlings i.e. those shorter than 50 cm and therefore not included in the tree survey. Record vernacular species names, provided by local community members, and work with a botanist to obtain scientific names.

Use the format in Data Sheet 4, to record the data.

Data Sheet 4 – Ground Flora

SAMPLE UNIT ID #:	Date:	RECORDER:
Ground Flora Within 5-m Radius Circle		
Structural Feature	SCORE	
Rock		
Bare soil		
Leaf litter		
All grasses		
All other herbs		
Shrubs		
Tree crown cover		
SPECIES	SCORE	Tick if tree
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
<i>Sparingly or very sparsely present, cover very small</i> <i>Plentiful, but of small cover value</i> <i>Very numerous or covering at least 5% of area</i> <i>Any number of individuals covering 1/4 to 1/2 of area</i> <i>Any number of individuals covering 1/2 to 3/4 of the area</i> <i>Covering more than 3/4 of the area</i>	0.1 1 2 3 4 5	Page No.

4.2 - Watershed functions

4.2.1 – Soil water storage at field capacity

Hypothesis: leaf litter production by regenerating trees will increase the organic matter content of the top soil. This will increase soil water storage capacity of the soil, enabling greater water absorption during the rainy season and the retention of more water for longer into the dry season.

Per cent moisture content at field capacity is the maximum amount of water that can be held per gram of dry soil against the force of gravity. It is closely and positively related to soil organic matter content. It is usually the per cent moisture content of the soil at the end of the rainy season and determines how long plants can survive, without wilting or leaf fall, as the dry season progresses. Soils with high per cent water content at field capacity can absorb a higher percentage of the water delivered by each rainfall event, before surface runoff begins to occur. They also store more water to drain into streams over a longer period during the dry season. Therefore, as field capacity increases, stream flow is maintained for longer into the dry season.

Collect 3 replicate samples of top soil (0-5 cm deep) in each SU. In the lab, place a piece of filter paper in a glass funnel in a conical flask. Tip one soil sample into the funnel until the soil surface is about 1 cm below the edge of the filter paper. Pour in water until the level of water is just above the soil surface. Wait until the water has drained through the soil into the flask and no more drips fall from the funnel. At this stage, the soil contains the maximum possible amount of water held against gravity. Tip out the wet soil into a pre-weighed aluminium foil tray. Weigh the tray + wet soil sample. Subtract the weight of the tray to arrive at the weight of the sample of wet soil (W1). Dry the sample in an oven over night to constant weight and reweigh the sample. Subtract the weight of the tray to arrive at the weight of dry soil (W2). Field capacity is calculated as:

$$(W1-W2)/W2*100$$

Calculate the mean and variance of the field capacity of the three replicates for each SU.

4.2.2 - Sediment load

Hypothesis: ANR will increase the cover of leaf litter over the soil surface and increase tree root density. This will help to prevent movement of soil particles during rainfall events. An increase in soil field capacity (4.2.1) will reduce and delay surface runoff. In combination, these effects should reduce the sediment load in streams draining an ANR site, more rapidly than the reduction in sediment load expected in streams draining unassisted regeneration in the control site.

Ideally, this should be done in separate stream tributaries; one draining the control site and one draining the ANR site. Collect 1-litre water samples from the lowest point where the stream leaves the plot(s). Record the GPS location of the sampling point. Once per month, fill 3 x 1 litre bottles with stream water. For each triplicate water sample, weigh a piece of dry filter paper with high precision. Place the filter paper in a funnel. Shake the water sample and slowly pour it through the filter paper. Place the filter paper + sediment in an oven and dry to constant weight overnight. Sediment load should be calculated in mg per litre as follows:

$$(\text{Weight of filter paper + dry sediment}) - (\text{Original weight of dry filter paper})$$

Calculate the mean and variance of the sediment load of the three replicates for each sampling time.

4.3 - Carbon stocks

4.3.1 - Woody vegetation

Equipment: the GBH data for trees (GBH>5 cm) from Data Sheet 3

Calculate the above ground dry biomass of each tree recorded within each SU, using GBH data from Data Sheet 3. For each tree > 5 cm GBH, in each circle, calculate the diameter at breast height DBH (cm) by dividing GBH by pie π (3.14159) and use an allometric equation to estimate the dry mass of the above-ground parts of each tree. Allometric equations predict a difficult-to-measure parameter (i.e. tree dry biomass) from an easily measured one (i.e. DBH). They are originally constructed by felling trees of different sizes and then drying and weighing the whole tree. A graph is plotted of dry mass vs DBH and the equation, derived from the shape of the curve, can subsequently be used to predict tree dry mass from DBH, without the need for any further destructive sampling.

Basuki et al. (2009), showed that the most accurate prediction of the total above-ground dry biomass (kg) of a tree takes the form of:

$$\exp [c + \alpha \ln(\text{DBH})]$$

...where exp means “e” (Euler’s number, 2.71828) raised to the power of ... , c and α are constants, “ln” stands for natural logarithm and DBH is diameter at breast height (cm). Basuki *et al.* showed that the constants c and α vary greatly among tree species (from minus 2.193 to minus 1.098 for c, and from 2.142 to 2.339 for α , for common timber trees in lowland dipterocarp forest in Indonesia). However, Brown (1997) presented generalized equations for tropical dry forest types (annual rainfall <1,500 mm with distinct dry season) and moist tropical forest types (annual rainfall 1,500 – 4,000 mm, no or short dry season).

$$\text{Dry forest: } 2.71828^{[-1.996 + (2.32 \times \ln(\text{DBH}))]}$$

$$\text{Moist forest: } 2.71828^{[-2.134 + (2.53 \times \ln(\text{DBH}))]}$$

Although Basuki et al. demonstrated considerable errors in their use; we have not been able to find any more accurate equations, specific for the forest types and/or tree species in the project participating countries. Equations, derived from felled trees for each location, would probably be more accurate but tree felling is not practical for this study. Bear in mind that errors in biomass value, derived from such equations, are large (often in excess of $\pm 50\%$), but if the same equations are used consistently in all follow-up surveys, at least we should be able to i) detect if ANR results in a relative increase in carbon stocks and ii) compare relative carbon stocks among the sites.

To calculate the mass of roots of each tree, multiply the above-ground biomass by 0.37 for tropical evergreen forest or 0.56 for drier tropical forest (IPCC, 2006; Table 4.4, or consult Cairns et al. (1997) for ratios for other forest types) and add the result to above-ground biomass.



Sum the estimated total tree dry biomass (above-ground + roots in kilograms) within each SU and enter the values into Data Sheet 7. The carbon content of dry tropical wood varies considerably among species, but the average value is around 47% (IPCC, 2006 (Table 4.3); Martin and Thomas, 2011). Therefore, an estimate of carbon in trees in each SU can be obtained by multiplying the dry biomass of all trees in an SU (derived from the above equations) by 0.47. This procedure is automatically carried out within the downloadable spreadsheet of Data Sheet 7.

4.3.2 - Herbaceous vegetation

Equipment: shears, scissors, 1 x 1 m wire quadrat, large plastic bags, large paper bags or newspaper and stapler, oven, portable electronic balance.

Within each circular SU, crop exactly 1 sq m of the ground vegetation with a pair of shears, as close as possible to the soil surface. Weigh an empty plastic bag with a portable electronic balance to the nearest gram. Place the vegetation sample into the plastic bag and weigh. Derive the wet sample weight by subtracting the bag weight. Label the plastic bag. Transfer all samples to the lab and transfer them to paper bags (or wrap in sheets of newspaper). Dry the samples either in sunshine for 5 days or in an oven, if available, overnight at 80°C. Make sure no material is lost during the transfer and drying process. Then reweigh the samples. Use Data Sheet 5 to calculate the dry mass of herbaceous vegetation (in g/m²) and add the results for each SU to the other carbon data to Data Sheet 7.

Data Sheet 5 – Mass of Ground Vegetation

SU	Field			Lab			
	Weight plastic bag (field) (g)	Wet sample + bag (g)	Wet sample weight (g/sq m)	Weight paper bag (lab) (g)	Dry sample + bag (g)	Dry sample weight (g/sq m)	% Water content
1	e.g. 30	506	476	21	320	299	37.2
2							
3							
4							

4.3.3 – Soil

Equipment: soil corer 5 cm diameter, sample bags (approximately 15 x 20 sq. cm), masking tape for labeling, marker pens, large zip-lock bags, trowel, drying room, drying oven, battery operated portable electronic balance (to 0.01 g), hand-held electronic pH meter.

At 4 random points within each SU, push the hand held electronic pH meter into the soil to about 3 cm and record the reading.

Organic layer: sample the organic layer (litter and humus), if present, with a metal ring, 30 cm in diameter. Carefully remove dead leaves and twigs from within the ring and place the whole sample in a labeled plastic bag. In the lab, place the samples in pre-weighed metal foil trays, dry the samples (in direct sunlight for several days or overnight at 60°C) and weigh them. Enter the dry mass of the whole sample into Data Sheet 7.

Soil samples: the project budget limits analysis of soil carbon to only 10 samples per country (5 from control plots and 5 from ANR plots). Since changes in soil carbon storage, due to ANR treatments, are likely to be detectable first in the upper soil layers, we will sample only the top 15 cm of soil, which usually accounts for 20-40 % of the carbon in the whole soil profile (Kavinchan, pers com.) (About 80% of carbon can be found in the top 1 m of soil).



Collect a soil sample from every alternate SU. Push a soil corer 5 cm in diameter into the soil to a depth of 15 cm and gently withdraw the corer keeping the soil column intact. Reject any cores with thick roots, large stones or with soil missing from parts of the core. Place each sample into a separate plastic bag and label each bag with SU identification number and date etc. with an indelible marker. Use a portable electronic balance

to measure the wet mass of each sample (subtract the weight of the plastic bag).

In the lab, determine the dry mass of soil particles in the whole soil core (0-15 cm) by first placing each sample into a pre-weighed aluminium foil tray and air drying each sample. Separate roots and stones from each dry sample with a 2 mm mesh sieve. Then return all sieved material to the aluminium foil tray and continue to dry at 105°C for a further 24 h. Check if the soil is completely dry by drying it for a further 12 h and recording no further weight loss. Weigh the completely dry soil with an electronic balance and enter the value into Data Sheet 7.

Thoroughly mix the dry material from each core sample and take a sub-sample of around 500 gm of each dry core material. Ship the subsamples to: Dr. Prasit Wangpaka-pattanawong, Biology Department, Faculty of Science, Chiang Mai University, for carbon content analysis by the Walkley-Black technique (Nelson and Sommers 1982, Walinga et al. 1992). Enter the % carbon content into Data Sheet 7.



Weigh the whole core sample, wet in the field, and dry in the lab.

Data Sheet 6 – Soil Properties

RECORDER:	DATE:	CORE DIAMETER:
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SU NO.	SAMPLE CODE	LAYER	WEIGHT BAG (G)	WEIGHT BAG + WET SAMPLE (G)	WEIGHT WET SAMPLE (G)	SAMPLE DRY WEIGHT (G)	% MOISTURE CONTENT	p _H
1		LITTER						
		Soil 0-15						
2		LITTER						
3		LITTER						
		Soil 0-15						
4		LITTER						
5		LITTER						
		Soil 0-15						
6		LITTER						
7		LITTER						
		Soil 0-15						
8		LITTER						
9		LITTER						
		Soil 0-15						
10		LITTER						

5 – ANALYSIS

5.1 – Vegetation

5.1.1 – Effects of ANR treatments on natural regeneration

If ANR treatments are effective, the number/unit area of regenerants > 50 cm tall and their growth rates should increase more in the ANR site than in the control site. Furthermore, the mortality of small regenerants should be lower in the ANR site.

On the ANR site, more tree seedlings smaller than 50 cm tall (uncounted in the ground flora) should grow into the >50 cm size class (counted on Data Sheet 3) compared with the control site. From the data collected during the second monitoring, count the number of new regenerants, recorded in each SU, which are taller than 50 cm, but which were **not** labeled in the first survey (i.e. they were shorter than 50 cm in the first survey). Calculate the means (and SD's) for the ANR and control sites and perform a t-test, to determine if the difference between the means is significant.

For each labeled regenerating, surviving in **both** surveys, calculate the relative growth rate (RGR) as follows:

$$\frac{\ln H (2^{\text{nd}} \text{ survey}) - \ln H (1^{\text{st}} \text{ survey}) \times 36,500}{\text{No. days between measurements}}$$

...where $\ln H$ = natural logarithm of regenerating height (cm). RGR is an estimated annual percentage increase in size. It takes account of differences in the original sizes of the regenerants, so it can be used to compare regenerants that were larger at planting time with those that were smaller. The same formula can be used to calculate relative growth rates of root collar diameters and crown widths. To determine if RGR differs between the ANR and control sites, perform a t-test to compare the mean RGR values of each species with more than 5 surviving individuals on each site (over combined SU's)

In each SU, count the number of regenerants recorded as dead in the second survey and express as a per cent of the number of live regenerants counted in the first survey. Exclude tree stumps and trees > 5 cm GBH from the count. Calculate the mean value and SD for the ANR and control sites and perform a t-test, to determine a significant difference in mortality between the means. To refine the analysis look at how mortality rates differ according to the original size of the regenerants. Divide them into classes according to original height (50-100 cm, 100-150 cm ...etc.) and calculate the mortality in each size class. Mortality should be higher for the smaller size classes, compared with the larger size classes. Differences in mortality, compared between the ANR and the control sites, should be much greater for the smallest size class, but smaller for the larger size classes.

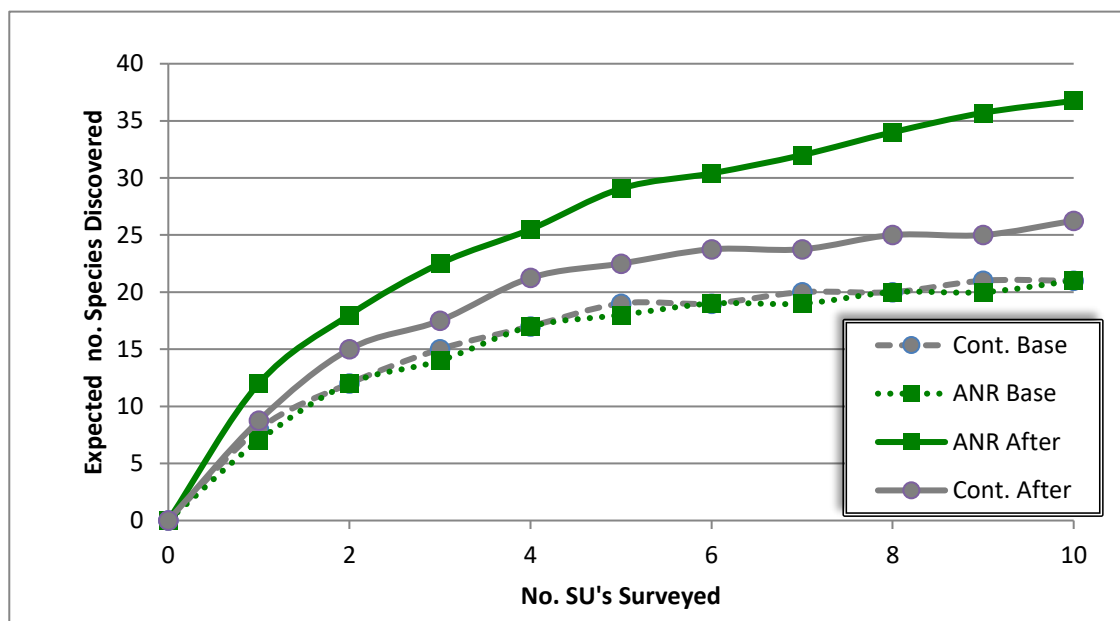
5.1.2 – Effects of ANR treatments on vegetation diversity

Construct species/area graphs using Coleman’s equation (Hubbell and Foster, 1983):

$$s(a) = S - \sum_{i=1}^S (1 - a)^{n(i)}$$

... where $s(a)$ is the expected number of species in a fraction (a) of the total area surveyed (i.e. $a=0-1$), S is the total number of species encountered and $n(i)$ is the number of individuals of each species over all ten plots (i.e. $i=1$ to S). The equation is solved for different values of 'a' and the resulting curve of $s(a)$ vs. 'a' is plotted.

These curves can be plotted for both the regenerant dataset and the ground flora dataset. It is expected that, between the first and subsequent monitoring events, the curve will rise in the control plot, due to **un**assisted natural regeneration. However, if ANR treatments are effective, the curve should rise significantly more for the ANR site datasets, as shown below.



This result can be confirmed by calculating Hill’s Diversity Numbers (N_0 , N_1 and N_2) (Ludwig and Reynolds, 1988), which should also increase more over time in the ANR site than in the control site.

N_0 = no. of species (species richness)

$N_1 = 2.71828^H$

... where $H = \text{minus} \sum_{i=1}^S [(p_i) \times \ln(p_i)]$

$N_2 =$

$$\frac{1}{\sum_{i=1}^S (p_i)^2}$$

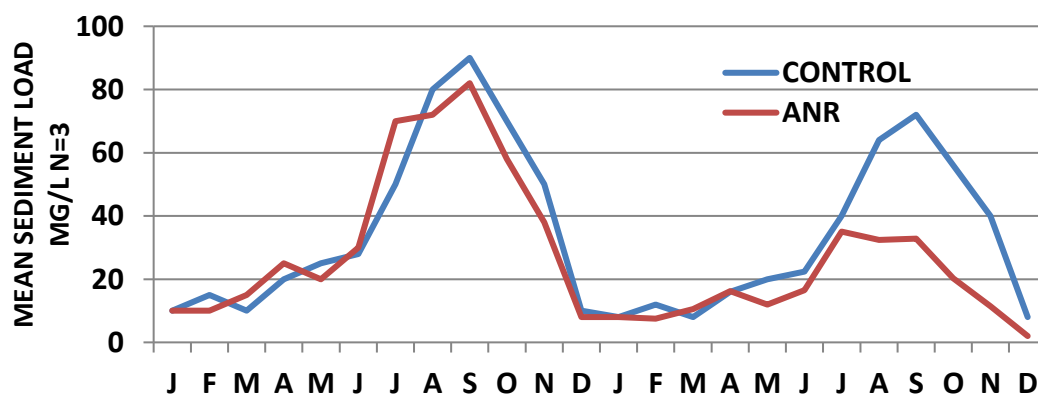
... where p_i is the number of individuals of each species (or Braun-Blanquet score) as a proportion of total number of individuals (or Braun-Blanquet score) of all species in all SU's in each site. Example calculation is below:

	Number of individuals or score					
	$n(i)$	p_i		$p_i n p_i$		p_i^2
Species A	1	0.053		-0.155		0.003
Species B	2	0.105		-0.237		0.011
Species C	4	0.211		-0.328		0.044
Species D	1	0.053		-0.155		0.003
Species E	3	0.158		-0.291		0.025
Species F	1	0.053		-0.155		0.003
Species G	2	0.105		-0.237		0.011
Species H	1	0.053		-0.155		0.003
Species I	1	0.053		-0.155		0.003
Species J	2	0.105		-0.237		0.011
Species K	1	0.053		-0.155		0.003
Total individuals (N)	19	1	H	2.26	LAMBA	0.12
N0	11		N1	9.59	N2	8.40

The successful effects of ANR treatments would also be indicated by a significantly larger increase, over time, in the mean per cent cover values of leaf litter, shrubs and tree crowns and a significantly larger decrease in rock, bare soil, grasses and other herbs in the ANR site, compared with the control site.

5.2 - Watershed functions

Calculate the mean sediment load (mg/litre) of the triplicate samples collected each month and plot a graph of sediment load vs. month over several years. Use time series analysis to confirm the presence of a significant effect. Please note that the effects of ANR on the soil erosion may only become apparent after many years, so an effect during the present project (1 yr) is not expected. Also, this analysis is only valid if two streams are monitored; one draining *only* the ANR site and the other draining *only* the control site. If there is a mix of land uses on-site, changes in the management or extent of any of those land uses may overshadow any changes in sediment load due to ANR treatments.



5.3 - Carbon stocks

The results from field and lab work provide dry mass quantities in terms of gm or kg per cm² or m². We use the international standard of 47% carbon content (IPCC, 2006 (Table 4.3); Martin and Thomas, 2011) to convert the dry mass of vegetation and litter to carbon and the lab result of soil carbon analysis to determine the amount of carbon within each soil core sample. Furthermore, all measurements must be converted into the same units i.e. metric tonnes of carbon per hectare, for carbon accounting. 1 hectare = 10,000 m² or 100,000,000 cm². 1 metric tonne = 1,000 kg or 1,000,000 gm.

Use the data from each SU to estimate a value for carbon in metric tonnes per hectare (tC/ha), then calculate the mean and variance of these estimates and carry out a t-test, to determine if there is a significant difference between the control site and ANR treatment site. Carbon is expected to accumulate on both sites, as both assisted and non-assisted regeneration proceed (unless there is a fire) but, if ANR treatments are effective, it should accumulate more rapidly on the ANR site than on the control site.

Copy and paste this web address into your browser address bar and it will take you to a drop box page. Click download to open an Excel spreadsheet, which will convert your measured values to tC/ha:

<https://www.dropbox.com/s/x7n1liagsxr8fns/Data%20Sheet%207%20-%20Carbon%20accounting%20calculations.xlsx>

Enter biomass and soil data ***in the units indicated*** into the blue cells of the spreadsheet. The spreadsheet will automatically calculate carbon as tC/ha. The spreadsheet uses the formulae below for conversion.

For **trees**, enter the total dry biomass (above ground + roots) of all trees in each SU (kg). This is multiplied by 0.47 to convert dry biomass to total carbon in trees (kg/SU). To convert kg to metric tonnes, result is divided by 1,000 and to convert “per m²” to “per ha”, the result is multiplied by (10,000/SU area (m²)) as follows:

$$\text{Trees tC/ha} = \frac{\text{Dry biomass all trees (in an SU) summed (kg)} \times 0.47}{1,000} \times \frac{10,000}{78.5 \text{ (m}^2\text{)}}$$

Results for ground flora are produced as grams dry biomass per m² for each SU. This is multiply by 0.47 to convert biomass to carbon. The result is divided by 1,000,000, to convert grams to metric tonnes/m². The result is then multiplied by 10,000 to convert “per m²” to “per ha”, as follows:

$$\text{Herbaceous veg. tC/ha} = \frac{\text{Mean dry mass of all ground flora samples (g/sq. m)} \times 0.47 \times 10,000}{1,000,000}$$

Results for **litter** are produced as grams dry matter per sample (circles 30 cm diameter). So conversion to tonnes C/ha is as follows:

$$\text{Litter tC/ha} = \frac{\text{Litter Sample dry mass (g)} \times 0.47}{1,000,000} \times \frac{100,000,000}{\text{sample area (cm}^2\text{)}}$$

For top soil, the measurements obtained are total mass (g) dry soil particles in a core 15 cm long x 5 cm diameter and the per cent carbon content from the lab analysis. The carbon in the sample is determined by multiplying the sample dry mass by the per cent carbon content/100. The derived mass of carbon is divided by the cross sectional area of the core to get a value “per cm²”. The result is multiplied by 100,000,000 to get a value “per ha” and divided by 1,000,000 to convert grams to metric tonnes.

$$\text{Soil tC/ha} = \frac{\text{Core dry mass} \times (\% \text{ carbon content}/100)}{(3.14159 \times (\text{core radius (cm)})^2)} \times \frac{100,000,000}{1,000,000}$$



Data Sheet 7 – Carbon (download this spreadsheet from DropBox and copy your data into the blue cells)

COUNTRY:	SITE:	DATE:
LITTER SAMPLE DIAMETER (CM): 30	SOIL CORE DIAMETER (CM): 5	

MEASUREMENT>>	DRY BIOMASS					CARBON				
	All trees (above-ground + roots) summed in each SU	Herbaceous vegetation	Litter	Soil sample whole core dry mass (0-15 cm)	Soil % organic carbon content	Trees	Herbaceous vegetation	Litter	Soil	TOTAL CARBON
UNITS>>	kg all trees in each SU	g/m ²	g/ whole sample	g/whole sample	%	metric tonnes/ha				
Example	150	950	30	590	2	8.98	4.47	1.99	60.10	75.54
CONTROL										
SU										
1						0.00	0.00	0.00	0.00	0.00
2						0.00	0.00	0.00	0.00	0.00
3						0.00	0.00	0.00	0.00	0.00
4						0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00	0.00
6						0.00	0.00	0.00	0.00	0.00
7						0.00	0.00	0.00	0.00	0.00
8						0.00	0.00	0.00	0.00	0.00
9						0.00	0.00	0.00	0.00	0.00
10						0.00	0.00	0.00	0.00	0.00
									Mean	0.00
									SD	0.00
ANR TREATED										
SU										
1						0.00	0.00	0.00	0.00	0.00
2						0.00	0.00	0.00	0.00	0.00
3						0.00	0.00	0.00	0.00	0.00
4						0.00	0.00	0.00	0.00	0.00
5						0.00	0.00	0.00	0.00	0.00
6						0.00	0.00	0.00	0.00	0.00
7						0.00	0.00	0.00	0.00	0.00
8						0.00	0.00	0.00	0.00	0.00
9						0.00	0.00	0.00	0.00	0.00
10						0.00	0.00	0.00	0.00	0.00
									Mean	0.00
									SD	0.00

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