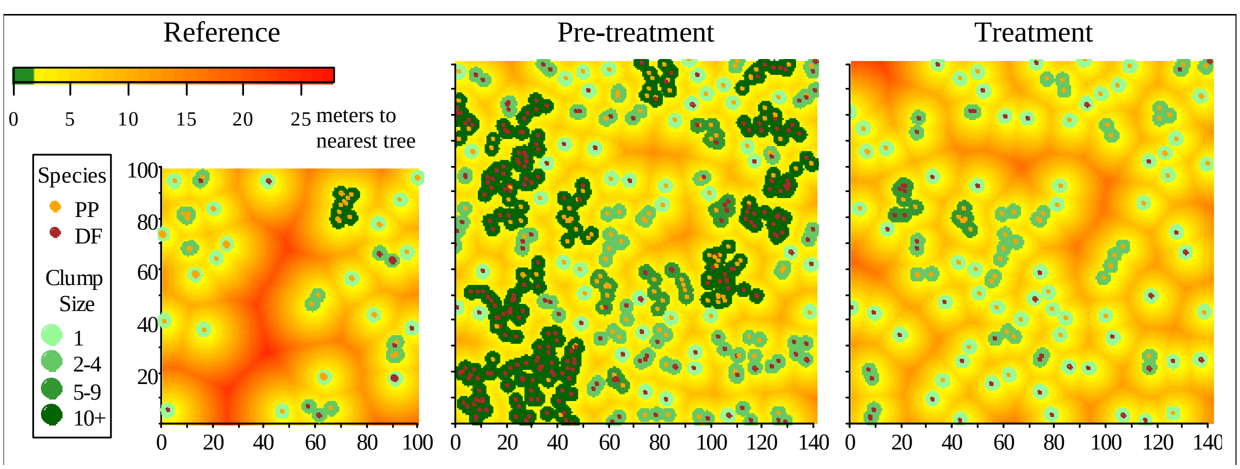
The ICO Approach to Quantifying and Restoring Forest Spatial Pattern

Implementation Guide

Version 2.0. November 2013



The ICO Approach to Quantifying and Restoring Forest Spatial Pattern: Implementation Guide

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Background

This document is intended as a "How To" guide for managers and stakeholders wishing to implement the Individual, Clumps, and Openings (ICO) method for silvicultural prescriptions and/or monitoring. In this second version of the guide, we have included a number of updates and re-organized the guide to emphasize the prescription development section. We added a section on "Quickmapping", which is an abbreviated form of stem mapping using a GPS unit. Links to several Arc tools and documents we have developed for quickmapping are included. This guide has two companion papers that we strongly recommend reading. The scientific basis for the method is established in Larson and Churchill (2012). An operational case study was conducted in 2009-2011 and is presented in Churchill et al. (2013a). In addition, we have incorporated the ICO method into a larger framework for dry forest restoration in a new field guide (Franklin et al. 2013).

Acknowledgements

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Contents:

I. Introduction

The ICO method is a stand-level tool to restore the mosaic patterns of individual trees, clumps, and openings commonly found in pine and mixed conifer forests that have intact, frequent-fire regimes (Larson and Churchill 2012), as well as other forest types (Larson and Churchill 2008). Many managers and stakeholders across the west have an intuitive understanding that frequent-fire forests were not uniformly spaced, and that "clumpy-gappy" patterns played an important functional role. Scientifically, there is a broad consensus that to increase resilience, treatments should seek to restore the range of patterns found in forests with intact disturbance regimes (Covington et al. 1997, Allen et al. 2002, North et al. 2009, Stephens et al. 2010, Franklin and Johnson 2012). In addition, there is increasing recognition that strict basal area and spacing-based prescriptions do not achieve this goal (North et al. 2009) (Fig 1.)

The ICO approach originated to address the challenge of translating the general goal of a "clumpy-gappy" pattern into marking guidelines. A number of other similar methods have been developed across the west (e.g. Moore et al. 1999, Bailey and Covington 2002, Graham et al. 2007, Knapp et al. 2012, North and Sherlock 2012); the ICO method is another tool in the toolbox. The method is also a valuable tool to monitor whether patterns created by any treatment approach are consistent with a defined set of reference conditions. In developing the method, we sought to balance the need for:

- Concrete, ecologically based targets for spatial pattern that can be objectively monitored
- Flexibility to work with current stand conditions (e.g. tree condition)
- Operational simplicity and efficiency.

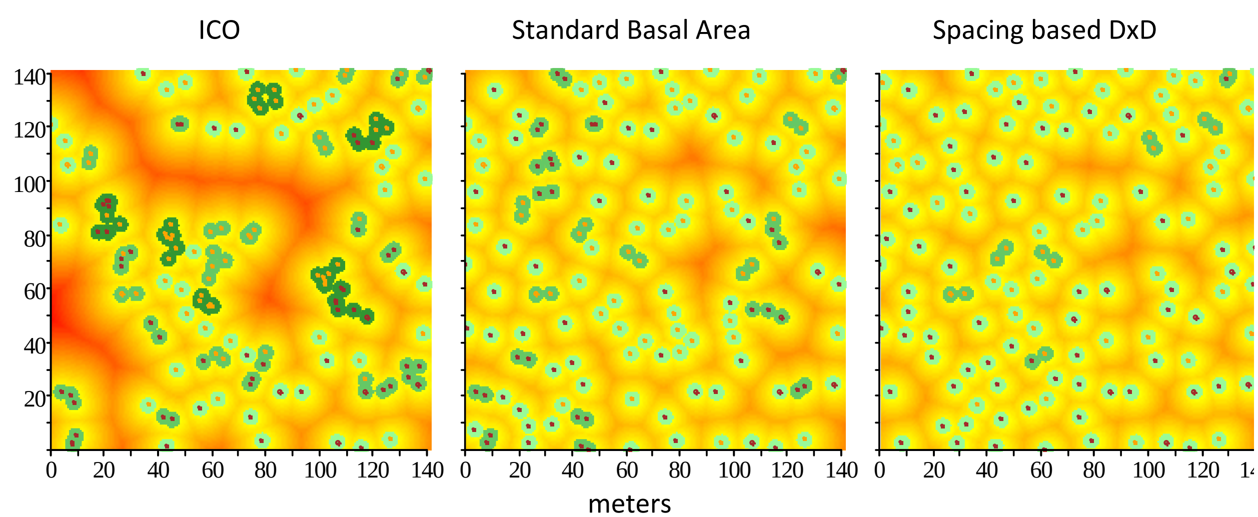

Figure 1. Five acre stem maps comparing ICO, basal area, and spacing based DxD prescriptions from Churchill et al. (2013). Darker color green indicates large sizes of tree clumps. Background yellow, orange, and red color indicates the distance to the nearest tree and openings.

The ICO approach is based on conceptualizing and quantifying forest structure in terms of widely spaced individual trees, tree clumps of different sizes, and openings. ICO prescriptions are based on targets for these 3 elements that typically originate from reference stands. Clumps are defined by a maximum distance between trees, based on the average distance at which mature and old trees have interlocking crowns. Instead of marking for a specific range of basal areas, marking crews identify and track the number of clumps they retain, while incorporating other leave tree criteria. We have found this to be a more intuitive and efficient approach than marking for basal area as individual trees and tree clumps are readily visualized. By focusing on marking clumps, small to medium sized openings (up to ~1/3rd acre) are generally created automatically. Specific instructions in marking or contractor cutting guidelines are typically need for larger openings.

Reference spatial information is obtained from stem map reconstructions of historical conditions or contemporary forests that have the desired structure and pattern (e.g. un-harvested stands with minimally altered or restored fire regimes, or old growth stands for forest types with long fire return intervals). Stem maps from a particular project area are not mandatory to implement the method, however. Regional reference datasets exist for most areas of the interior western US (Larson and Churchill 2012), and the number of available datasets is expanding rapidly. An effort is underway to quantify regional reference pattern envelopes through a meta-analysis of all existing reference stem maps and make the information available to managers. Obtaining the necessary reference data to implement the ICO method is covered in detail in section VI. If reference data does not exist for your area and is not feasible to collect, professional judgment can be used to set spatial targets.

The ICO approach has been implemented on a number of public and private ownerships and the method is fully operational. Numerous sales have been marked, sold, and cut, and many more are currently being planned and marked. Although most projects are in pine and dry mixed conifer forests, several are being implemented in coastal Douglas-fir and Northern Rockies moist mixed conifer. The method can be used for any forest type where reference targets exist or can be defined. However, the ICO method only deals with stand-level spatial pattern targets. ICO does not address the need for larger scale heterogeneity across project areas, watersheds, etc. We recommend that it be used in conjunction with a landscape-level assessment and planning approach (e.g. Ager et al. 2012, Hessburg et al. 2013). Finally, the ICO method is still evolving, and this document will be updated again. Comments and feedback are welcome!

II. Assessing Whether the ICO Approach is Appropriate for Your Stand:

The ICO method is a version of variable density thinning and can generally be applied in stands appropriate for commercial or non-commercial thinning treatments. It can also be integrated into individual tree and group selection approaches. Use of the full method is generally not necessary in stands where there is a strong need to dramatically reduce one species and/or regenerate another. Tree selection in these cases is primarily or exclusively based on species conversion (e.g. remove white fir and retain all ponderosa pine), although the ICO method can still provide guidance for large clump retention. Simiarly, regeneration type treatments designed to treat major forest health concerns typically don't require full use of the method. In terms of stand types, the method is most useful in:

- Relatively even-age, single-cohort stands: These may be pre-commercial sized or older plantations, as well as naturally regenerated stands that originated after high severity disturbances or intensive logging. "Black bark" pine stands are ideal for the ICO method.
- Uneven-age stands where selective logging removed most of the old trees. These stands are typically dominated by an 80-120 year old cohort of trees, but also contain scattered pre-settlement (old) trees and younger cohorts.
- Stands dominated by old trees: Simply retaining old trees can restore most of the desired spatial pattern without the need for specific guidelines. However, the ICO method can still be useful for setting pattern targets for younger cohorts.

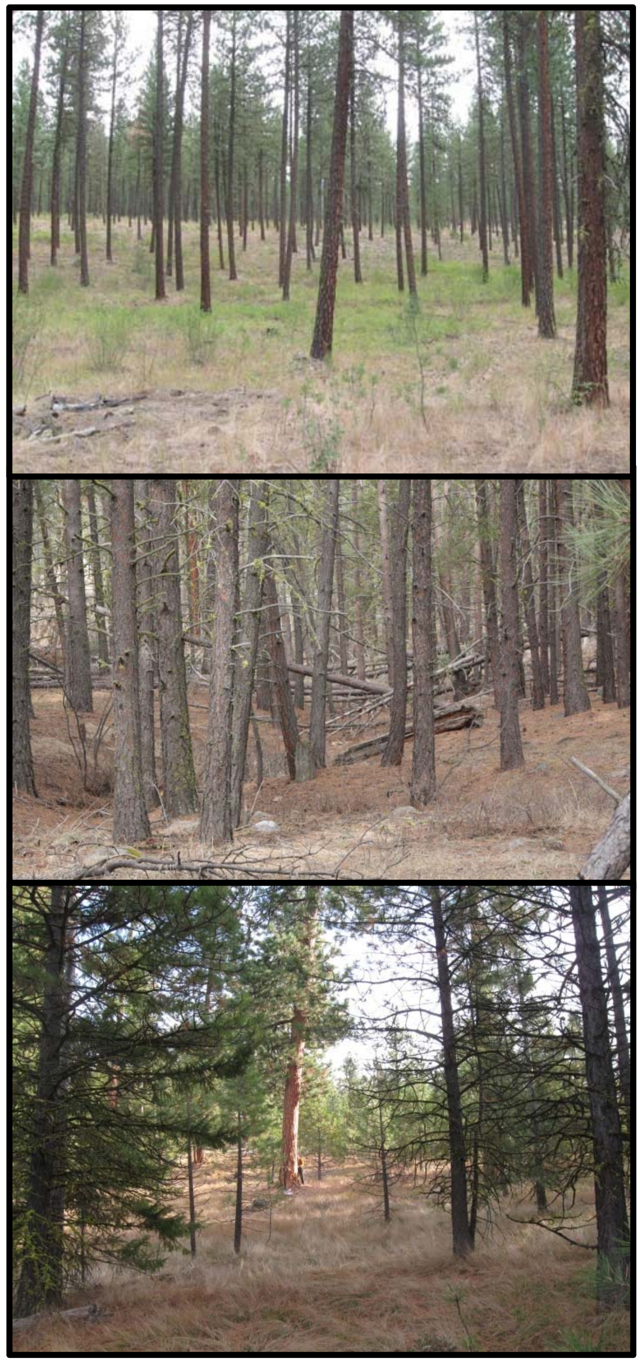

Figure 2. Stand types where the ICO method is most useful: plantations, "blackbark" stands of naturally regenerated pine, and stands with varying combinations of pre-settlement and younger trees.

III. Prescription and Marking Guide Development:

ICO is a tool to achieve a desired spatial pattern in a stand-level treatment. It is not a stand-alone silvicultural system. When used in a dry forest context, it incorporates common tree and species selection guidelines for restoration and fuel reduction treatments (e.g. Agee and Skinner 2005, Peterson et al. 2005, Franklin et al. 2013), but adds explicit targets for spatial pattern. The goal of the ICO method is not to recreate the exact pattern and density of historical or contemporary reference stands, but to ensure that a mosaic pattern of individual trees, clumps, and openings is created that is within the range of desired conditions. Given the wide range of patterns found in natural forests, there is no optimal or correct pattern for an individual stand. Ideally, a range or envelope of desired conditions has been defined for the forest type you are working in (see section VI). As with any silvicultural approach, a combination of quantitative information and professional judgment is required in developing prescriptions. The following steps lay out the prescription development process: (A link to a worksheet for developing prescriptions is provided in section VII: "Companion Tools and Documents").

1. Identify skips and other special treatment areas

In most restoration treatments, portions of the stand will be treated differently than under the general thinning prescription. Areas are often left as untreated "skips" or "wildlife retention areas" (e.g. riparian buffers, dense multistory patches, dead wood patches, mistletoe patches, pole sized patches left to break up sighting distances, etc.), heavy thin areas (e.g. removing conifers around aspen clones), or special treatments for root rots etc. Guidelines for the number, size, location, and treatment of these areas should be developed first and are discussed in detail in Franklin et al. (2013).

In general, larger special treatment areas located on distinct biophysical microsites (e.g. riparian buffers) should be considered separate from the general thinning area and not count towards clump totals for stands. Smaller special treatment areas that are widely distributed in the stand can be integrated into the general marking and counted towards the clumps totals (e.g. dense overstory skips , or clumps of trees with mistletoe that need to be isolated, aspen release).

2. Consider the need for large openings

Openings are critical component of the structure, pattern, and function of dry forests. However, they are very difficult to delineate and quantify in low canopy cover forests. Instead of prescribing specific targets for openings, we have found that small to medium sized openings (up to ~1/3rd acre) are created in the course of general ICO marking and that the resulting openings are within the range of reference conditions. The combination of density targets, clumping targets, leave tree criteria, and existing tree pattern and condition will largely dictate where smaller openings end up. For openings larger than about 1/3rd acre, we have found that specific prescription guidelines are needed. These should be based on the size distributions found in reference stem maps or functional objectives such as wildlife habitat needs, snow retention, fire behavior, or light requirements of desired regeneration. The expected creation of openings from prescribed fire and other disturbances should also be factored in.

3. Determine the stand average density target:

An average BA, TPA, or SDI target for the stand should be selected that is appropriate for the species, structure, site productivity, and management objectives. Stand average targets can come from historical reference stands, density management tools, or a combination of both (see Franklin et al. (2013) for a full discussion of setting density targets). In dry forests, the number and size of old trees must be factored in to the density target. To use the ICO method, the target must be converted to TPA (see Table 1). A lower diameter cutoff also needs to be specified for the TPA target. This should be the lower limit in the contract or cutting guidelines given to the marking crew or contractor.

Table 1: Basal Area to TPA conversion chart. TPA values for each QMD and BA level are shown in the main portion of the table. Values are derived from the formula: TPA = BA / ((QMD)^2 * .005454).

		Basal Area (ft2/ac)							
		40	**60**	**80**	**100**	**120**	**160**	**180**	**200**
QMD (in)	**14**	37	56	75	94	112	150	168	187
	16	29	43	57	72	86	115	129	143
	18	23	34	45	57	68	91	102	113
	20	18	28	37	46	55	73	83	92
	22	15	23	30	38	45	61	68	76
	24	13	19	25	32	38	51	57	64
	26	11	16	22	27	33	43	49	54
	28	9	14	19	23	28	37	42	47
	30	8	12	16	20	24	33	37	41

4. Determine the appropriate distance to define clumps:

The definition of a tree clump is based on the average inter-tree distance at which mature/old trees of the dominant leave tree species have clearly interlocking crowns and form patches of contiguous canopy. This distance can vary from 15 to 22’, depending on site productivity of the stand. The ICO method requires that a single distance be used to define and identify clumps in the field. A default distance of 20’ is recommended for ponderosa pine stands. Trees are members of the same clump if they are within this distance of at least one other tree in the clump. Individual trees are those with no neighbors within the distance. Measuring the distance from tree face to face, as opposed to tree pith to pith, allows facilitates use of a laser range finder to measure distances. Remember that clumps will have a range of distances between trees up to the selected distance. In stands where clumps have been thinned out in prior entries, a maximum distance of 20 or 23’ typically still allows for clumps. Although these clumps will not have the range of closely spaced tree found in historic forests and may not be as suitable for some functions, their canopies will still eventually form clumps.

Figure 3: Photos of 4 clumps sizes. A widely spaced individual is shown in the top left, a small clump (2-4 trees) on the bottom left, moderate clump (5-9 trees) on the top right, and large clump (10+ tree) on the bottom right.

5. Obtain targets for clump proportions

ICO prescriptions are based on a target proportion of trees in different sized clumps within a stand. Proportions are just the percentage of trees, or TPA, that are in different sized clumps. Basal area proportions can be used, but we have found TPA targets to be more straightforward to use. Ideally, a table summarizing clump proportions for a range of reference conditions in your area is available (Table 2). If not, instructions for developing one are provided in section VI. Targets can also be generated from field observation and professional judgment when reference data is not available. Proportions for clump sizes should be lumped into four or five bins for operational simplicity. We use 4-5 bins (Fig 3): individual trees, small clumps (2-4 trees), medium clumps (5-9 trees), and large clumps (10-20+ trees). Note that when instructed to leave a large clump (e.g. 10-20 trees), marking crews often have difficultly leaving the upper end of the size range (e.g. a 18, 19, or 20 tree clump). Thus adding a fifth bin for "super clumps" may be necessary (e.g. 15-20 trees or 20-25+ trees), especially if the upper size range of clumps is desired.

Targets should be grouped into different levels of clumping (Table 2). We have found that in dry forests, stands with low clumping levels are dominated by widely spaced individuals and small clumps, and have very few moderate and large clumps. Stands with high clumping levels can have up to 50% of the trees in moderate to large clumps, and as few as 20% as individuals. These proportions will vary based on the clump distance (inter tree distance) being used (see Table 2). At longer inter-tree distances, more trees are in clumps.

Table 2 Summary of clump proportions from nine 5-12 acre reconstruction plots in ponderosa pine and Douglas-fir plant associations in the Eastern Washington Cascades. One plot from Eastern Oregon was also included. The 10-15 and 16-20 clump sizes can be added together into a single clump size, or used separately. This table should not be used in other areas without consulting the authors. The shaded row are the target proportions selected for the example prescription in steps 5-6.

		Clump (Bin) Size (# of trees)				
Clumping Level	Clump Distance	1	2-4	5-9	10-15	16-20
High	5m (17')	0.30	0.40	0.20	0.05	0.05
Mod	5m (17')	0.45	0.40	0.10	0.03	0.02
Low	5m (17')	0.55	0.40	0.05		
High	6m (20')	0.25	0.30	0.25	0.10	0.10
Mod	6m (20')	0.35	0.30	0.20	0.10	.05
Low	6m (20')	0.50	0.40	0.10		

6. Select target clump proportions for your stand:

To set targets for individual stands, each stand must be matched with a specific reference stand or an average condition from a set of appropriate reference stands. For example, using Table 2, select a low, moderate or high clumping target for each individual stand. Then, select the row with your inter-tree distance and pull out the target clump proportions for each bin size (see shaded row in Table 2). To set targets for individual stands, consider the following:

- Assess the number and clumping levels of live old trees in your stand. The clump percentage targets should accommodate retaining existing old trees.
- Direction and structure stage targets from landscape analyses. For example, if surrounding stands have been simplified by past thinning, consider a high clumping level.
- In stands with few old trees, assess any evidence of historical tree patterns (live old trees, old stumps, old snags & downed logs) (Fig. 4). Estimating the approximate percentage of trees in moderate and large clumps is generally possible in a field walk through. As large and moderate clumps drive overall clumping levels (Table 1), this can inform what that site supported in terms of low, moderate, or high clumping levels.

Figure 4: Assessing the clump size of pre-settlement tree patterns: old live trees, stumps of former old trees, and snags and downed logs from old trees.

- Assess the extent to which healthy, young trees of the desired species are clumped in your stand. While some inferior trees should be left to make up larger clumps, higher clumping levels may not be possible in some stands.

7. Generate clump targets for the whole unit:

Using your target TPA and selected target clump proportions, follow the steps below to generate clumps targets for the treatment unit (See table 3 for an example).

1. Multiply the target percentages for each clump size by your TPA target to get the target number of trees per acre each clump size (Multiply the columns in row 2 x row 3 in table 3 below).
2. Divide each total by the average number of trees for that clump size to derive the target number of clumps per acre. For example, the 5-9 tree clump size has an average size of 7. Divide columns in row 3 by row 1.
3. Multiply the clump per acre targets by the total stand acreage to get clump targets for the whole unit (row 4 x unit acreage). The unit targets are what go directly into the marking guidelines. Final targets should be rounded to whole numbers; we generally round upwards.
4. For young stands with small trees (e.g. pre-commercial thinning treatments), consider increasing the target for the largest clump size by 5-10%, and reducing the target number for individuals to balance out the total TPA target. This will ensure that sufficient numbers of large clumps exists in the future and hedge against higher anticipated rates of mortality in large clumps vs. individual trees. As clumps self-thin out over time, they will progressively move down in clump size. Alternative, thickets of regeneration can be retained and not counted in the clump targets.

Table 3: Calculating clump targets for a unit using the ICO method.

	Clump Size				
	Individual	Small	Moderate	Large	Super
Number of trees in clump	1	2-4	5-9	10-15	16-20
1. Average clump size for bin	[1]	[3]	[7]	[12]	[17]
2. Target Clump Percentages	0.25	0.30	0.25	0.10	0.10
3. Trees per acre (Target TPA 40)	10	12	10	4	4
4. Clump target per acre	10	4	1.4	0.33	0.22
5. Clump target per unit (Unit acres = 20)	200	80	28	7	5

8. Define leave tree criteria

Leave tree criteria are generally similar to typical dry forest prescriptions (see Box 2). This will include retaining old, pre-settlement trees, as well as species preferences, size class preference (e.g. thinning from below), tree health or crown ratio criteria, selection for wildlife trees, etc.

Box 1. Sample ICO prescription and marking guidelines.

Sample Marking Guidelines from ICO method

Spacing & clump targets

- Leave an average of 40 TPA over the 20 acre unit. Ignore all trees <5" dbh.
- Leave 200 individuals trees. These are trees with no neighbors within 22'.
- Leave 80 small clumps (2-4 trees); 28 medium clumps (5-9 trees), 7 large clumps (10-15 trees), and 5 super clumps (16-20 trees).
- Clumps have trees within 20' of at least one other tree in the clump.

Leave Tree Criteria:

- Retain all old trees; generally over 150 years.
- Around old PP, remove young trees for 1-2 driplines—OK to keep 1-2 large/vigorous trees occasionally.
- Favor ponderosa pine
- Thin from below removing mostly trees <21" with poor crowns (<35% live crown ratio). Retain occasional mid-story and understory trees as individuals (>45 LCR) or to make up clumps (can be inferior trees).
- Retain 2-5 green wildlife trees per acre: trees with forks, broken tops, or large branch platforms.

Special Treatment Areas within 20 acre General Thin Area: (All leave trees count toward clump targets)

- <u>Mistletoe patches</u>: Retain only old trees that are mistletoe infected and isolate them as clumps or individuals with a 40-50 foot host-free (80-100%) buffer beginning at the last visible sign of infection.
- <u>Snags/Down wood skips</u>**:** Protect snags > 20 inches with a no-cut buffer (~30' radius).
- <u>Create 2 large openings</u>: These should be ~0.75 – 1 acre and wavy. Retain any old trees within opening and 1-2 larger younger trees. Centerline locations for these openings have been flagged
- <u>Visual and Regeneration skips:</u> Leave 2-3 additional thickets of regeneration and pole size trees in 0.1 – 0.5 acre patches to break up sighting distances. These trees should generally be trees <5" dbh and *not counted towards clump targets.*

Special Treatment Areas outside of 20 acre General Thin Area: (Layout prior to marking)

- <u>Riparian buffers:</u> Layout 50' no-cut buffers on streams and seeps in unit. Use wavy boundaries to work with topography and include some multistory, complex patches. These buffers were not part of the 20 acre thinning unit and do not count towards clump targets.

IV. Implementation

1. Layout and marking

We recommend laying out larger special treatment areas, especially those with unique, biologically important features, prior to the general marking. Marking crews should be aware of the location of these areas before general marking to avoid confusion with the clumping guidelines. To describe and lay out the sinuous openings commonly observed in reference stem maps, managers on the Okanogan-Wenatchee NF lay out a center flag line for a specified distance and all trees within a distance range (e.g. 33-66') of the line are marked for removal before the general marking begins. Specialists or experienced layout personnel lay out the center line and factor in edaphic factors and disturbance processes.

Once special treatment areas are located and laid out, the general marking can begin. We stress that the target number of clumps per acre are not rigid targets, but instead *approximate averages* that should be obtained over the whole stand, or sections of the stand. It is critical that markers work with existing stand conditions and the leave tree criteria to locate clumps. Some areas will likely end up with more clumps and others less, depending on existing clumpiness, tree condition, and other factors. The goal is not to get the exact number of clumps on every acre, but to ensure that a clump/gap structure is created.

When moving through a stand, consider these guidelines to decide what to do at each tree group or small area (<1/10th acre):

a. Leave all old trees. Where high numbers of old trees exist, most of the clumping targets will be met with the old trees.
b. For young trees, assess what the tree group naturally looks like and has the potential to become. For example, many trees already appear to be clustered in a clump of a certain size. Widely spaced trees with large crowns often already appear to be individual trees.
c. Consider what you have already marked and progress towards clump targets.
d. Look ahead to see what opportunities for clumps of different sizes exist.
e. Always balance leave-tree criteria with clumping targets. For example, don't try to force clumps by leaving excessive numbers of marginal trees. Leaving some marginal trees is generally desired to facilitate self-thinning processes and snag creation.

f. Sometimes clumps will be left, other times they will be thinned through (except for old trees). Don't spend too long thinking about any one clump. Make a decision and let the clump targets and tracking provide parameters to inform decisions as you go.

g. Large and moderate sized clumps may be located close to other large clumps. Do not worry about spacing them out, focus instead on where good opportunities for clumps exist.

h. Intentionally leave small openings (<~1/3rd ac), or expand existing openings, where this fits with clumping and leave tree criteria. Do not worry about "filling growing space".

2. Tracking during marking:

We have found that real time tracking of the number and size of clumps that are marked greatly improves implementation effectiveness. For either cut or leave tree marking, each person in the marking crew can carry a card with pre-calculated clump targets for individual markers and track clumps as they go. Crew members can check in from time to time to see how the crew as a whole is progressing towards the clump targets.

Figure 5: Marking out clumps and real time tallying of clump totals. Note that in this case, a 4 tree clump is being thinning to a 2 tree clump. The 4 tree clump could have been left, or just the tree on the right left to create an individual. Cut tree marking marking is being used along with "cruising as you go".

A preferred approach is to have one person track clump retention for the whole crew. Crew members shout out to the tally person when they leave a clump of particular size. The tally person then periodically informs the crew on how they are progressing towards the targets for each clump bin size. The crew can then adjust their marking as needed (e.g. fewer large clumps, more individual trees, more small clumps). Also, tallying the average diameter of clumps can be added to the clump tracking to inform whether basal area targets are being met and to assess the size range of trees in clumps. An experienced marker can tally and mark at the same time.

For stands over 20 acres, we recommended breaking the stand into 20-40 acre sub-units for marking so that marking crews can track their clump totals within a reasonable amount of area. Alternatively, the tally person can carry a GPS with the stand boundary loaded to get a sense of how much of the unit the crew has covered. Progress toward the clump targets can then be periodically checked relative to how much ground has been covered. Ideally, large skip locations can also be loaded in the GPS to give crews a heads up. Another method is to install check plots to ensure that the overall density target is being met. These can be 1/10th – 1/5th acre fixed area count plots, or variable radius plots for BA targets, can periodically be put in. The average target should *not* be met on most plots due to the high levels of variability created by this method. Instead, the average of 8-10 plots should get close to the target. Tracking is especially important when marking crews are learning this method and adjusting their "eye" as to what different density and clump targets look like.

Tracking is also real time implementation monitoring. Once marking in a stand is completed, clump totals in each bin size and overall leave or cut tree density can be tallied. Crews will know if they achieved the target or not, without having to rely on subjective assessments of whether they followed the prescription. If either clump or density targets are way off, the crew can immediately go back into the stand and address the problems. Results can also be shared with stakeholders. This will build trust in the ability of the agency to implement restoration prescriptions effectively. We have found that tracking initially adds around 10-15% in extra time to mark a stand, but this is reduced as crews get used to the method. Tracking will likely only be necessary in a sample of stands once crews are experienced with the method, or when new crew members are being trained. Sample tracking paper datasheets are available; see section VII: Companion Tools & Documents. In additional, a tablet and phone app is being developed to track clumps during marking. Once crews are familiar with the method, we have found that marking ICO treatments takes the same amount of time as standard basal area marking. Markers generally appreciate the quantitative guidance on how many and what size to leave.

Finally, it is critical to remember to work with the stand and not to force the target number of clumps. The final clump tallies will generally vary somewhat from the targets, especially if clumping of old trees was not estimated well. If final clump tallies are consistently above or below targets, bias for or against clumping may exist in the crew.

3. Cruising and DxP

For cut tree marking, cruising can be done in conjunction with tallying clumps. We have found this to be the most efficient way to cruise these types of sales. However, plot cruising post marking can also be done. To date, all ICO prescriptions have been done by marking. However, ICO prescription could be put in a Designation by Prescription (DxP) contract and implemented by a logging contractor. Although a DxP sale has not been done yet, contract markers have implemented ICO prescriptions.

A DxP approach often requires a cruise prior to full marking of the stand by the purchaser. This can be done in 2 ways. First, cruise plots can be "cut" to the average density target; the variation in leave tree density and volume removal is assumed to average out over the unit. ICO prescriptions have generally resulted in similar volume per acre removals to BA prescriptions, so this assumption is generally reasonable. The second option is to retain clumps of different sizes in the cruise plots based on the proportions in the marking guidelines. For example, if marking guidelines call for retaining 50% of trees as individuals, then 50% of the trees in the cruise plots should be individuals. If 10% of the trees are prescribed to be in large clumps, then approximately 10% of the trees retained in the cruise plots should be in large clumps. This approach requires tracking trees across plots.

A DxP ICO prescription could also be implemented by an experienced machine operator, particularly in a young, simplified stand. We are currently developing a tablet app to track clumps that could be used by an operator to track moderate and large clumps. Contact the authors for ideas on how contract compliance could work with a DxP approach. The ICO approach will not work with a straight Designation by Description approach.

V. Monitoring using a "QuickMap"

The ICO approach can be used to quantify and monitor the patterns and structural changes created by any treatment, whether the ICO method or another approach was used to develop the prescription. Spatial and structural metrics generated from the monitoring data can be used to objectively determine whether the treatment (1) met the desired structural, density targets (e.g. basal area), and species composition criteria and (2) created a spatial pattern that is within the range of variation of a given set of reference stands. Clump size distributions (clump proportions) from the treated stand can be compared with a reference dataset. A second metric, the empty space function or F-test, can be used to quantify and compare openings (see Churchill et al. 2013). For more detailed analysis, additional spatial pattern metrics can be also used (Larson et al. 2012). Reference stands can be pre-settlement, historic stands, or contemporary stands that have the desired structure and intact pattern/process dynamics (e.g. an active fire regime). If an ICO prescription was used and tracked during marking, "implementation monitoring" of the clump proportions and leave tree density (BA and TPA) has already been done. However, assessing the total area and spatial arrangement of openings may still be desired.

A major barrier to using the ICO approach for monitoring has been the need to install a stem map. To address this, we have developed a "QuickMap" method that uses GPS unit and a set clump distance to quantify the clump size distribution (clump proportions) and create an approximation of a stem map using an AccMAP tool from which openings can be quantified. The method is designed to facilitate a quick assessment of stand level treatments and does not require extensive forestry knowledge, stem mapping, or specialized equipment. Any kind of treatment can be evaluated, whether an explicit ICO prescription was used or not. Below we lay out field methods for QuickMapping as well as the analysis steps.

1. Determine the inter-tree distance to define clumps:

The ICO method requires that a single distance be used to define and identify clumps in the field. This distance is generally based on the average inter-tree distance at which mature/old trees of the dominant leave tree species have clearly interlocking crowns and form patches of contiguous canopy. This distance can vary from 12 to 22', depending on dominant species in the stand. A default distance of 20' is recommended for ponderosa pine stands. Trees are members of the same clump if they are within this distance of at least one other tree in the clump. Individual trees are those with no neighbors within the distance. Inter-tree distances should generally be measured tree pith to tree pith to be consistent with how reference stem maps were analyzed.

2. Determine lower diameter cutoff for sampling:

This is the diameter at which trees are considered too small to be part of the tree population that will be monitored. The lowest diameter class that was reliably sampled in the reference dataset is the best cutoff, typically around 4-6” dbh. Often this is close to the merchantability diameter for treatments.

3. Define sampling area within stand:

This will depend on the number of people and time available for monitoring. Quickmapping is most efficient in groups of 2-4 people, and generally a small group can cover 10-20 acres in a day, depending on the density of the treated stand. The easiest method is to Quickmap the whole stand. However, this is not typically possible, so sampling 15-20% of the unit is recommended. Randomly locate 2-3 x 5-10 acre square, or rectangular, plots within the stand boundaries. The “Create Random Points Tool” in ArcMAP can be used to generate random plot corners. We recommended dividing the unit into halves or thirds and placing a random plot in each one.

Several options exist for locating the boundaries of the sample areas. Plot boundaries can be preloaded onto a GPS unit and determined in the field. Alternatively, boundaries can be flagged. Existing unit boundaries, roads, or other features such as streams can be also be used. Flagging boundaries is generally recommended for crews larger than about 4 people, unless they split into separate teams. Including all trees within a 10-15’ buffer outside of the plot boundary is recommended. This provides insurance against plot boundaries that may be slightly off and improves the power of the spatial metrics.

Figure 6: Quickmapping a dry mixed conifer stand.

4. Identify and record clump information:

The crew should systematically move through the plot(s) and identify all individual trees and clumps. This is done by measuring the distance to the nearest neighbor for each tree (tree pith to pith) and seeing if it is less than the set clump distance from #1. Trees are members of the same clump if they are within the clump distance of at least one other tree in the clump. Individual trees, which are considered 1 tree clumps, are those with no neighbors within the distance. A combination of ocular estimates and measurements with a tape or good laser rangefinder can be used.

For each clump, record the following:

a. ID #. Using the first initial of person plus a sequential number is recommended
b. Field tag: Flag or staple a brightly colored paper tag or regular flagging to trees that have been identified. Write the clump ID# on the tag/flagging for at least 1 tree in the clump. This ensures that trees are not missed or double counted. All trees within a clump do not need to be flagged/tagged, only the perimeter trees.
c. Clump size: number of trees in the clump. If the clump extends outside of the plot, record the total clump size irrespective of plot boundaries, but note the number of buffer trees (e).
d. Diameter & Species: One of three approaches can be taken for the whole stand, depending the type and accuracy of information needed for monitoring:
    - The average dbh of all trees in the clump can be estimated by selecting an average sized tree and measuring it. Ocular adjustments can be made as needed. Inches is assumed and used in the ArcTools.
    - Trees can be grouped by species and/or size class and the average diameter of that class measured (e.g. 4 Douglas-fir trees with a 15” average dbh + 3 pine with 18” dbh). Snags are typically considered a separate class. Old trees can also be considered separate.
    - The dbh and species of each tree in the clump can be recorded.
e. # of Buffer trees: If the clump is on the edge of the plot and is bisected by the boundary, record how many trees are outside the plot in the buffer zone.
f. Other Items: Items such as changes in plant association, habitat structures, etc. can be noted as deemed necessary for each clump.

5. GPS centerpoint of clump & record clump dimensions:

Depending on crew size, GPS information can be recorded separately from clump information or they can both be entered into the GPS unit. We have created an ArcPAD template file for this purpose. If clump information from #4 will be recorded separately from the GPS information, paper datasheets are typically the easiest way to go. See section VII: “Companion Tools and Documents” for links to the ArcPAD template file, as well as blank data sheets.

For each clump, locate and stand at the center and record the following:

a. GPS clump center point: recording with the greatest number of GPS positions possible. The number of GPS locations recorded will depend on the quality of the GPS unit, satellite availability, and crew speed. At least 25 GPS positions per point is recommended. For individual trees, stand next to the tree bole or use an offset if satellite coverage is an issue.
b. Clump shape: circle, line, or oval.
c. Azimuth and radius of major (longest) axis. For lines, this is the distance to the end of the line from the center point. For circles, it is radius (circles do not need an azimuth). For an oval, locate the longest axis. Using a good laser range finder will increase speed.
d. Length of minor axis for ovals only. This axis is perpendicular to the major axis.
e. GPS Line for large clumps: For clumps larger than 6-8 trees, especially those with an irregular shape that does not conform well to a line, circle, or oval, we recommend GPSing a line feature. Use a “polyline” with vertices, where points along the line are recorded at the major “corners” of the clump. The line does not need to be “closed”.

The following practices for GPSing are suggested

- In cases where the person with the GPS unit is working independently of crew members identifying clumps, the GPS person should track on a notepad the clumps sequentially for each clump marker to ensure that all clumps are GPSed.
- Use a GPS unit that has a precision level less than 5m, ideally <2m. Some recreational grade GPS units can achieve this level in open forest conditions, particularly those that connect with the GLONASS satellites. Precision is more important than accuracy as the position of clumps relative to each other is what matters for the spatial metrics, not the actual geographic location.
- If a GPS unit is being used that only has 1 field for additional data (e.g. Notes), enter the information from 5b-d separated by commas in that field.

6. Analysis

In order to determine whether the stands that were monitored have the desired structure and pattern relative to reference conditions, we recommend the following sequential analyses:

a. Derive basic summary metrics such as basal area per acre, tree per acre, relative species composition, diameter distribution, etc. Remember that the basal area and diameter distribution of a young stand may not be within the range of reference stands right after treatment. It may take many decades to get there.
b. Calculate the clump proportions and compare them to the reference dataset. Clump proportions can be derived in a spreadsheet from the QuickMap field data as clump membership and clump size are determined in the field. If you used a stem map to install a monitoring plot, see section VI for how to calculate the clump proportions.
c. Create a figure of the monitoring plot (e.g. Fig. 7). This is perhaps to most powerful way to communicate to managers, stakeholders, and marking crews the results of the treatment.
d. Derive the empty space function, F(t), for the plot to evaluate openings relative to the reference conditions. See section VI for an explanation of this metric.

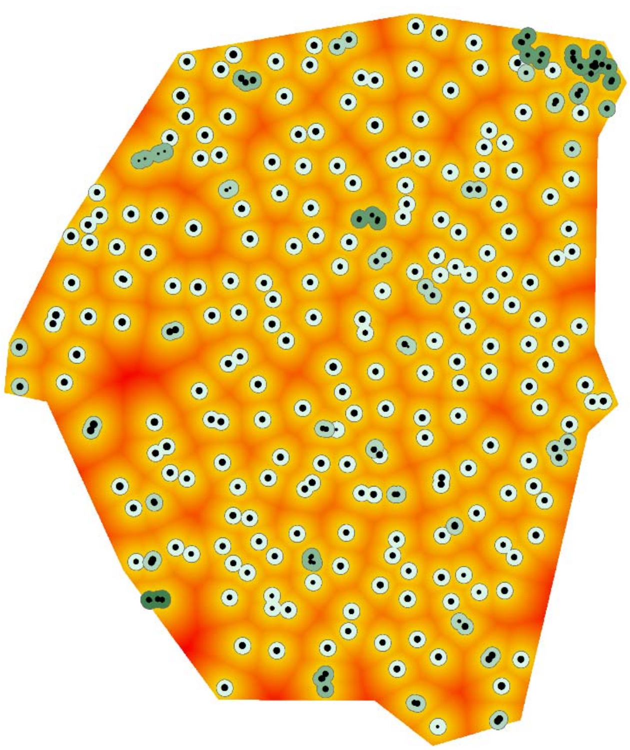

Figure 7: Stem map produced by the Arc Tool from a monitoring QuickMap done in a treated stand.

7. AcrMAP & Excel Spreadsheet Analysis Tools

We have built a python tool for the ArcMAP toolbox and a companion excel file to perform the tasks described in step 6. It was designed to be used with the ArcPAD template form we constructed, but can be used with GPS and field data gathered in other formats. See section VII: “Companion Tools and Documents” for links to these tools. The Arc Toolbox converts a Quickmap to a stemmap, produces figures (Fig. 7), and the F(t) open space metrics. The excel document calculates clump size proportions and compares both clump proportions and the F(t) metrics to a reference dataset (Fig. 8).

B	C	D	E	F	G	H	I	J	K
Acres	10.4		Species Composition (BA)						
Live TPA	27.69		PP	50.5	100%				
BA Ft^2/AC	50.5		DF	0.0	0%				
QMD	18.3								
SDI	77.2								
			Clump Proportions						
Snag TPA	3.8		1	2-4	5-9	10-15	15+		
Snag BA	2.2		0.75	0.16	0.09	0.00	0.00		

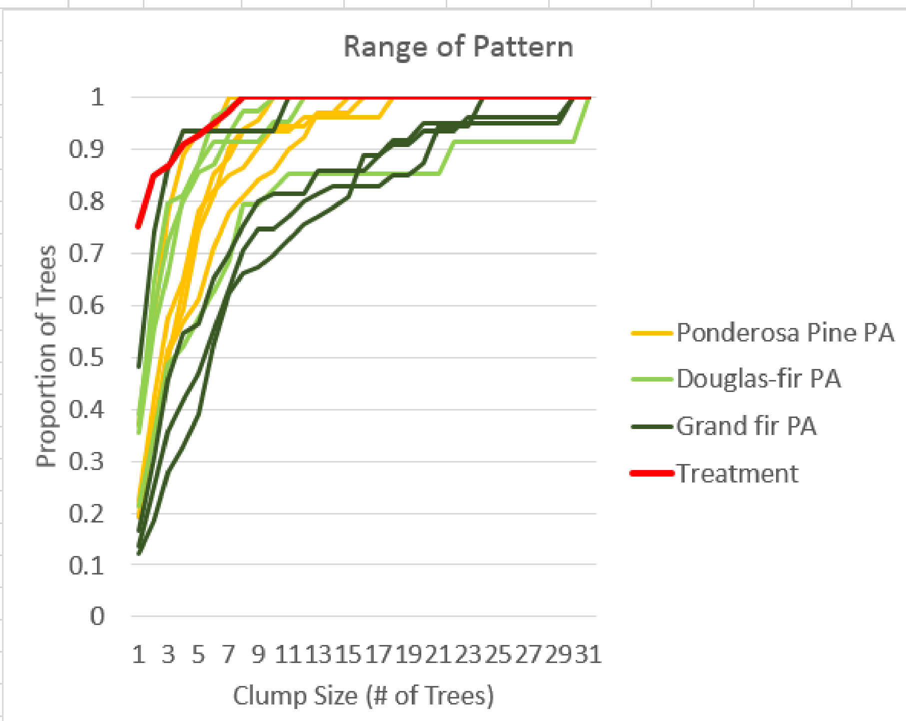

Figure 8: Excel spreadsheet where monitoring data from a treated stand is compared to reference stands. The figure shows the cumulative clump size proportion. Reference data is from the Malhuer National Forest and is broken into 3 different plant association groups (PA). Note that the treated stand is outside of the reference envelope, or right at the edge of it. Treated stand is shown in figure

VI. Obtaining Reference Stem Maps and Quantifying Pattern

A stem map based on x and y coordinates obtained by surveying tree locations forms the basis of quantifying the spatial reference conditions to guide prescription development (Fig. 9). Stem maps have been installed in many locations throughout the west (Larson and Churchill 2012). In some cases, reference spatial information may already be available and summarized in a way that it can be directly incorporated into ICO prescriptions. Such data exist and have been published for areas in Arizona (Abella and Denton 2009, Sánchez Meador et al. 2011), the eastern Washington Cascades (Churchill et al. 2013), the northern Rockies (Larson et al. 2012), and the Sierra Nevada (Lydersen et al. 2013). Reference datasets for using ICO in other forest types, such as coastal Douglas-fir or Pacific silver fir, also exit (Larson and Churchill 2008).

The first step in obtaining reference stem map data for ICO prescription development is to review the published reference stem map data (Larson and Churchill 2012), and also contact local and regional forest scientists to determine if unpublished datasets are available before going out and installing a new stem maps. Researchers are typically willing to share the raw x,y coordinate data from reference data sets for prescription development purposes. Most research datasets are collected using public funding—it is perfectly reasonable to ask researchers to share their data to help inform management efforts. Most researchers will be pleased that managers are interested in their work. If you are able to locate reference stem maps, you can skip to section 4.4 which describes the analysis process.

When suitable stem map data are not available, installing new stem maps in reference stands is necessary. The "QuickMapping" method discussed in the monitoring section (section V) can also be used for this purpose. Reconstruction of pre-settlement stands is the most common approach, but using current, un-harvested stands with minimally altered or restored fire regimes (e.g. Stephens and Fule 2005, Taylor 2010) is another option if such sites exist in the region and forest types being managed. In this section, we discuss procedures for installing reference stem maps (or quick maps) to obtain new reference data, as well as the procedures to analyze and summarize data (from either new or existing stem maps) it in a way that can be used in ICO prescription development.

Don't have reference data? Contact us for assistance.

If you have questions about obtaining and analyzing stem maps in order to use the ICO method, we can help. In cases where obtaining data is not immediately possible, we may be able to assist with data collection or provide suitable data from other locations to get started. See our emails on page 2.

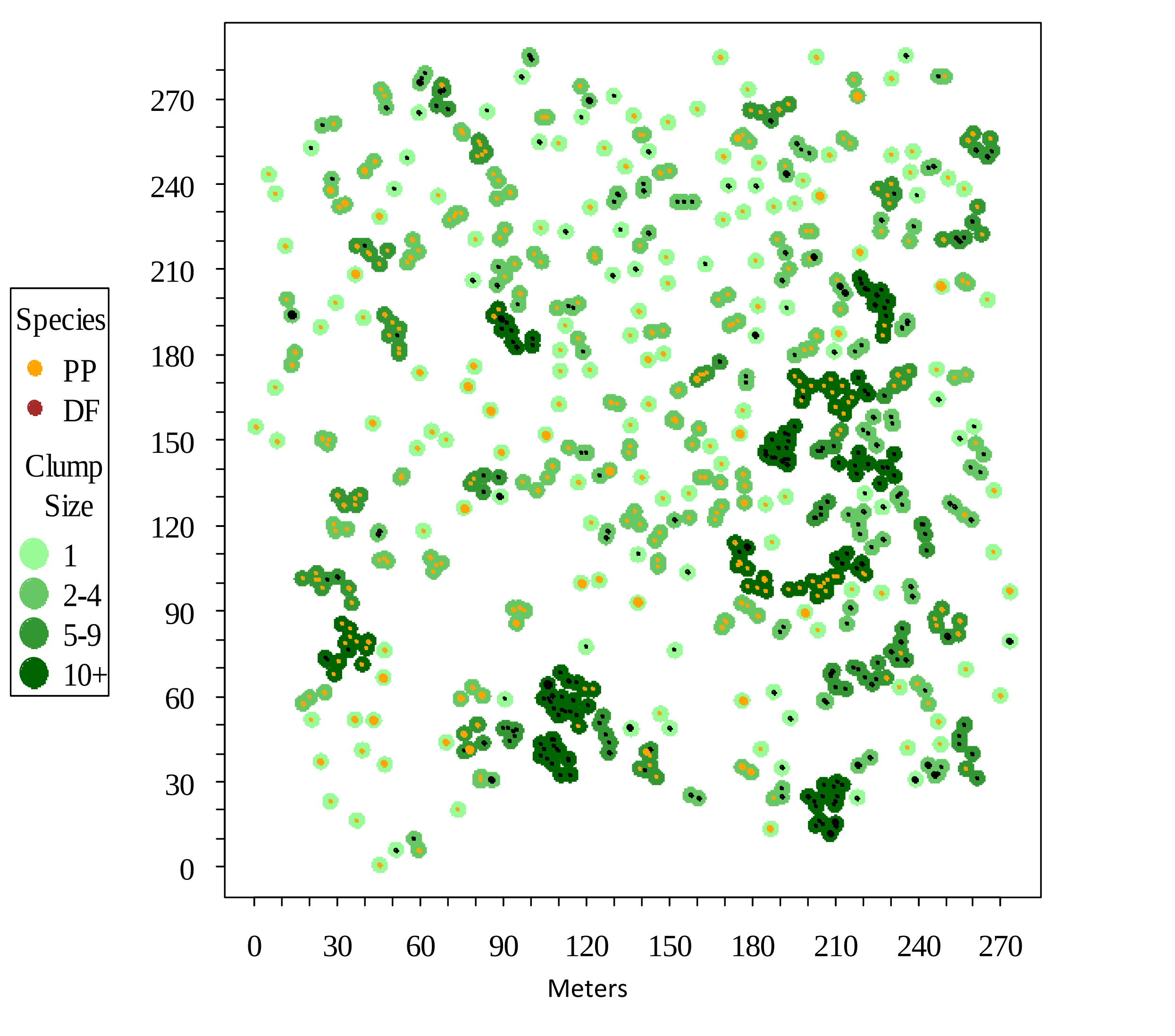

Figure 9. A ~13 acre stem map of pre-settlement trees near Naches, Washington. Three meter radius tree crowns are projected around each tree to illustrate formation of clusters using the Plotkin et al. (2002) algorithm.

1. Identifying appropriate sources of reference spatial data

Choosing the appropriate reference site(s) for a particular treatment unit is a critical decision and requires care. Ideally, reference condition data from multiple sites is available and can provide information on a range of patterns, or range of "clumpiness" and openness. Managers can then decide what point in the range is most appropriate for a specific stand given existing stand structure, species composition, forest health issues, edaphic factors, management objectives, and operational considerations. While judgment is required in this process, existing stand conditions often dictate what types of within-stand pattern is possible or desirable.

Reference maps should come from sites with similar species composition, environmental characteristics (i.e., climate, soils, topography), and historical fire regimes to the treatment unit(s) for which the ICO prescription is being developed. In practice, this means usually similar plant association groups (PAGs), habitat types, or ecosystem types. The reference site(s) and treatment unit(s) will rarely be perfect ecological matches—some professional judgment will be required. Managers may also desire to consider climate change adaptation when developing ICO restoration prescriptions. One way to do this is to use climate analog reference conditions—use reference sites that have current climates similar to the projected future climate of the treatment unit. The scientific basis and implementation details for using climate analog reference conditions are provided in Churchill et al. (2013).

2. Site selection criteria for new reference stem maps

After a pool of candidate sites have been identified using the general criteria outlined in the previous section, a series of additional screening criteria are applied. These criteria are oriented towards reference datasets in frequent fire forests. For sites that historically had long fire return, contemporary old growth stands are good candidates. From experience and simulation analysis we have found the minimum size for quantifying patterns of tree clumps in most dry forests is about 1 ha (2.5 ac). However, quantification of openings requires larger stem maps, usually around 3 to 4 ha (about 7 to 10 ac), depending on opening sizes. Thus, the next screening criterion is to identify a square area of at least 3 ha (180m on a side), ideally larger, with no roads, streams, or major shifts in soils or topography. Some variability in site conditions is inevitable, and in fact desirable. The goal is to ensure the reference plot does not straddle major breaks in habitat type of contain other features (such as a stream and riparian area) that would introduce too much variation.

Additional selection criteria should be considered, especially if the reference stem map will involve stand reconstruction methods.

a. Clear evidence of frequent fire (fire scars on stumps and live trees showing return intervals of 5-30 years) is desirable to confirm that the reference site has a historical fire regime similar to the treatment unit.
b. Stands that have not been logged or burned since Euro-American settlement and the onset of fire exclusion are ideal if reconstruction methods will be used because historical stand structures will be better preserved compared to logged and burned stands. Stands with histories of past high grade logging can also work if stumps are well preserved. It is generally

best to avoid sites that have been entered or burned multiple times, especially with periodic selection logging or wood cutting. Stands with two harvest entries can work as long as it is easy to identify the harvest date of different stumps.

c. Sites where detailed fire histories are available are desirable because these additional data are useful for interpreting reference data. However, such "bonus" data are not necessary.

3. Installing stem map plots to acquire new spatial reference data

In frequent fire forests, the basic procedure for generating new reference spatial datasets is to map the locations of all trees judged to have been present at some reference year. The reference year is typically chosen to approximate the date of effective fire suppression or major alteration to the historical forest (e.g., the onset of intensive domestic livestock grazing). Such dates typically range from 1865 to 1935, depending on the region and history of Euro-American settlement and management. Reference stem maps may also be installed in unlogged contemporary forests with restored or continuing fire regimes. Also, contemporary reference sites are generally the best options for forest types that historically had long fire return intervals and stand replacing fire. In such cases, the historical reference year does not apply.

Installing a stem map is a relatively straightforward surveying exercise. It can be done with tapes and compasses, with laser range finders and an electronic compass, high precision GPS and laser rangefinder/angle encoder, or with formal surveying instruments such as a total station. High precision equipment is not essential if the purpose of the stem map is to develop prescriptions because inter-tree distances are typically binned at a minimum resolution of 1 m in the data analysis process. As long as basic surveying procedures are followed to ensure data quality, relatively "low tech" equipment will work fine. Stem maps should be as square as possible to minimize edge effects. Rectangular plots are sometimes inevitable, but avoid plots where one dimension is 1.5 times longer than the other.

Figure 10: Survey station for a reconstruction stem map**.**

We generally recommend using a horizontal control survey to establish a network of control points within the area to be stem mapped. A closed loop traverse works well for this part of the procedure. Individual tree locations are then mapped by measuring the distance and angle from a control point to a target tree. Detailed procedures for these surveying procedures can be found in any introductory surveying textbook, such as Chapter 7 of Nathanson et al. (2006). Other mapping techniques are also appropriate, such as using high precision GPS with integrated laser rangefinder and electronic compass. Absolute "real world" coordinates (e.g., latitude and longitude or UTM) are not necessary for the purposes of creating stem maps—the x,y coordinate data can be in an arbitrary coordinate system. What is important for this analysis is relative tree positions (i.e., where trees are located with respect to each other), not their actual locations on the earth's surface

Figure 11: Historical logs, snags, and stumps.

Reconstruction stem maps present the additional challenge of determining what trees, both living and dead, were alive at the chosen reference year. For live trees we recommend using the methods developed by Van Pelt (2008) to visually identify old trees, augmented with increment cores to age questionable trees. For stumps, determining the harvest year is necessary. This can be done by consulting

Forest Service or other land management records, as well as coring a selection of live trees adjacent to stumps to ascertain a common release year. Several methods have been developed to estimate the age of snags and downed logs (Fule et al. 1997, Taylor 2004, Everett et al. 2007).

To use the ICO method, historic diameters of trees are not required. However, historic basal area, diameter distributions, and diameters of trees in different size clumps are often of interest. They offer useful ecological insight and information for prescription development. To reconstruct historic diameters, all snags, logs, and stumps must be "grown back" from their year of death to the reference year, and live trees grown back from the current year. Developing equations for this purpose is a major undertaking that requires coring a large number of trees and intensive analysis. If available, equations developed from studies on similar sites can be used.

Generally, high precision techniques like cross-dating tree rings will be too time consuming and expensive for reference stem maps used for prescription development. There is inherent uncertainty in estimating the ages of dead trees, even in the most precise and detailed research studies. We recommend consulting a regional ecologist for guidance on developing criteria to estimate ages of dead trees. As long as the uncertainty is acknowledged and accounted for in the analysis and interpretation, reference condition data can be used to reliably inform prescription development.

We have found that installing pre-settlement stem maps generally takes 0.5-1 days per hectare with 3-4 people. Productivity depends on pre-settlement tree density, current understory density (which affects line of site distances and efficiency of surveying measurements), slope, the mapping methodology being used, and the number of trees that need to be cored to determine age. The "QuickMapping" method discussed in section V takes approximately ½ the time compared to stem mapping. However, there are a number of issues to consider in deciding between quickmaps or full stem maps. Contact the authors for more information if you plan on using the QuickMap approach.

4. Quantifying within-stand patterns: individual trees and the clump size distribution

Once a reference stem map, or set of stem maps, has been obtained or installed, a clump detection algorithm from Plotkin et al. (2002) is used to quantify the number and sizes of tree clumps, and number of individual trees (Table 1). Only the x and y coordinates are needed for this algorithm, although additional analysis can be done with diameter and species information. The algorithm works as follows.

At a specified distance (*d)*, the stem map is partitioned into a set of unique tree clumps (or clusters). Trees are members of the same clump if they are within distance *d* of at least one other tree in the clump, as measured from tree pith to tree pith. There are no constraints on the shape of clump; they may take any form as long as all trees link to at least one other tree in the clump. Clumps may have only 1 tree, which are called individual trees that have no neighbors within *d*.

For a range of distances (*d*), the algorithm counts the number of clumps of different sizes, size being the number of trees in the cluster. The algorithm starts with a *d* value of 1 meter and is typically run up to 10m. The primary output of this algorithm is the "Clump Proportion Table". This is the proportion of trees in different sized tree clumps at different inter-tree distances (*d)*. The clump proportion table associated with the stem map in figure 9 is shown in table 4. Instructions for implementing the Plotkin algorithm in ArcGIS are presented in Box 2. The method has been programmed in the statistical program *R* and the code is available upon request.

Table 4: Clump proportion table that shows proportion of trees in different cluster sizes at different inter-tree distances (*d*).

	Clump Size (Number of trees)													
d (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14-20+
1	0.92	0.07	0	0.01	0	0	0	0	0	0	0	0	0	0
2	0.75	0.16	0.07	0.02	0	0	0	0	0	0	0	0	0	0
3	0.56	0.19	0.12	0.06	0.04	0.01	0	0.01	0	0.01	0	0	0	0
4	0.42	0.19	0.12	0.07	0.05	0.04	0.02	0.01	0.01	0.01	0	0	0.03	0.02
5	0.31	0.17	0.12	0.09	0.08	0.04	0.05	0.03	0.01	0	0.01	0.02	0.02	0.06
6	0.22	0.15	0.1	0.09	0.07	0.07	0.05	0	0.01	0.03	0	0.02	0.03	0.16
7	0.17	0.11	0.1	0.09	0.05	0.06	0.08	0	0.01	0.03	0	0	0	0.29
8	0.12	0.1	0.08	0.07	0.01	0.08	0.03	0.04	0.02	0.03	0.01	0.03	0	0.36

A single inter-tree distance is necessary to define clusters for the purposes of prescription development. We use the maximum distance at which trees generally have interlocking crowns and form patches of continuous canopy (Long and Smith 2000, Graham et al. 2007). Based on field observations of interlocking crowns in mature ponderosa pine trees (120+ years) in our project areas, we have generally used a distance of 6 m or 20'. Abella and Denton (2009) and Sánchez Meador et al. (2011) selected inter-tree distances close to 20' for northern Arizona ponderosa pine forests. While the distances at which tree crowns interlock vary considerably, using multiple distances would make marking guidelines operationally impractical.

To simplify prescription development and make implementation tractable, we then lump clump sizes together into 4-5 bins and add up the proportions for each bin. We recommend five bins or clump sizes: individual trees, small clumps (2-4 trees), medium clumps (5-9 trees), large clumps (10-15 trees), and super clumps (16-20+ trees). These bin sizes are based on functional differences between clump sizes: for example, 5-9 and 10-20 tree clumps contain “interior trees” that are more susceptible to competitive stress and insect related mortality, smaller clumps do not. Moreover, understory shading and micro-climatic effects begin occurring in larger clumps (~5+ trees), which affects understory species, wildlife use, and fire behavior. Managers may choose to collapse the large and super clump bins together.

A robust reference dataset is ideal for using the ICO method in a large project area where multiple stands will be treated. There is no single correct pattern or set of clump targets, but instead quantifying the range or envelope of pattern is necessary to avoid creating the same kind of heterogeneity in every stand. To make reference information most useful for prescription development, the set of reference stands you have can be summarized into low, moderate, and high levels of clumping (Table 5). Low clumping are stands with a high proportion of individual trees (~50%) and few large clumps, while high clumping stands have fewer individual trees and more trees in clumps. This information should be provided for the range of likely inter-tree distances that will be used in the field (e.g. 4,5,6,7 m).

Table 5: Summary of clump proportions from nine 5-12 acre reconstruction plots in ponderosa pine and Douglas-fir plant associations in the Eastern Washington Cascades. One plot from Eastern Oregon was also included. The 10-15 and 16-20 clump sizes can be added together into a single clump size, or used separately. This table should not be used in other areas without consulting the authors. At least some local sampling will likely be necessary.

		Proportion of trees in clumps Clump Size (# of trees)				
Clumping Level	Distance (*d*)	1	2-4	5-9	10-15	16-20
High	5m (17’)	0.30	0.40	0.20	0.05	0.05
Mod	5m (17’)	0.45	0.40	0.10	0.03	0.02
Low	5m (17’)	0.55	0.40	0.05		
High	6m (20’)	0.25	0.30	0.25	0.10	0.10
Mod	6m (20’)	0.35	0.30	0.20	0.10	.05
Low	6m (20’)	0.50	0.40	0.10		

Box 2. Instructions for implementing the clump identification (Plotkin et al. 2002) in ArcMAP 10.

Detecting tree clumps and individual trees using ArcMAP 10

1. Compile the stem map data in a text file with columns for x and y coordinates and any desired tree attributes (e.g., dbh, species, crown radii). Import this dataset using the ADD DATA => ADD XY tabs in the FILE menu. Convert to a shapefile.

2. Use the Buffer tool (in the Proximity toolset within the Analysis toolbox) to create a buffer of distance d/2, one half the intertree distance, around each point. This quantity d/2 is meant to approximate the crown radius of a "typical" overstory tree. Set the Dissolve Type option to ALL, which dissolves overlapping buffers, creating a reduced set of spatially non-overlapping polygons stored as a multipart polygon feature.

3. Apply the Multipart to Singlepart tool (in the Features toolset within the Data Management toolbox) to the output from step 2. This step assigns a unique ID to each polygon. The output of this step is a set of multiple polygon features that represent the tree clusters present at a given intertree distance, d.

4. Use the Intersect tool (located in the Overlay toolset within the Analysis toolbox), intersect the output of step 3 with the original point feature shapefile (the stem map data in step 1). This produces a table listing associations between individual trees and the unique clusters they form at the intertree distance, d.

5. The attribute table of the shapefile produced from step 4 can be summarized in terms of the cluster size distribution, number of single trees, etc. Sanchez Meador et al. (2011) provide some useful examples of how clump attributes can be summarized.

6. Repeat steps 1-5 across a range of d (e.g. 1-20 m) to explore how the number and attributes of tree clumps and single trees vary as a function of distance (d).

Note: The method described here can be modified to use measured or modeled crown radii for each tree in place of d/2 in Step 2.

5. Quantifying within-stand patterns: targets for large openings

Openings are a critical part of dry forests. Identifying and quantifying them in low density forests is challenging, however, as most openings are not well defined "gaps" (Fig. 12). Prescriptions that leave significant proportions of trees in clumps will automatically create a certain amount of small and medium sized openings (< ~1/3rd acre), especially if there are edaphic factors or disturbance agents creating openings. However, we have learned that creation of large openings must be specified.

The primary method we use to quantify openings is the empty space function, or F-test. This function, *F(t),* quantifies open space in terms of distance from the nearest tree (Diggle 2003). *F(t)* is the distance from a grid of points laid out across the plot, typically 1m apart, to the nearest tree. The distances from each gird point to its nearest tree are pooled to create a cumulative distribution. *F(t)* is calculated using a stem map of the tree locations. It can be calculated in ArcMAP using the Euclidean Distance Tool, but it is much easier to calculate in R. For a more detailed description of how to use and interpret the empty space function, see Churchill et al. (2013). Methods to translate *F(t)* results to guidelines for large openings are still being refined and will be discussed in the next update of this guide.

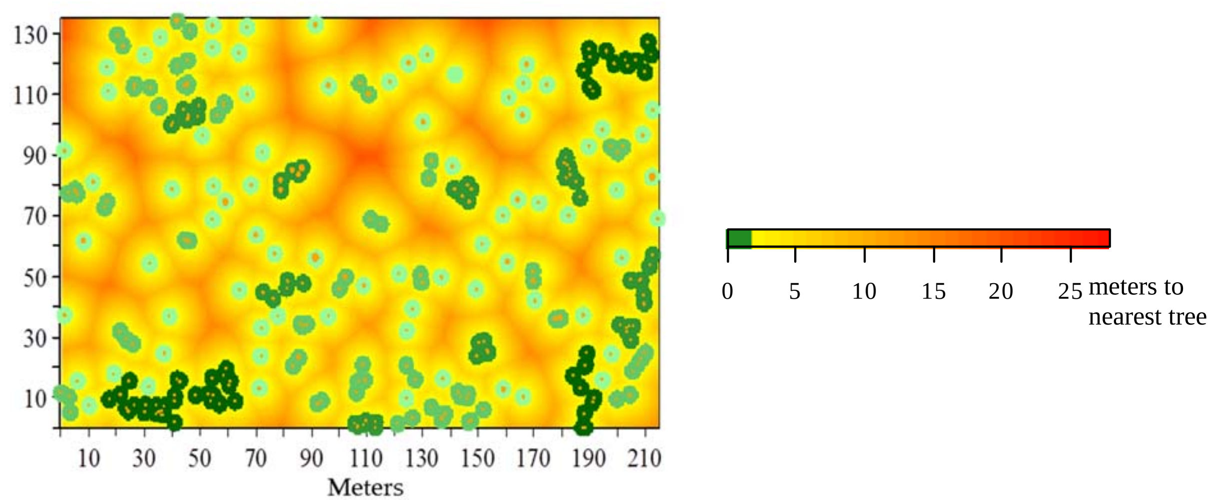

Figure 12: An ~8 acre stem map of pre-settlement trees in the Black Hills area of the former Klamath Reservation in central Oregon Background coloration indicates the distance to nearest tree or gap edge from the centers of a 1m cell grid- a graphical representation of the empty space function. The areas colored red orange in plots are areas that are approximately 20 m (66') from the nearest tree or gap edge. An opening with a relatively circular center of dark red has an approximate area of 0.3 ac (the area of a circle with a radius of 66'). The long, sinuous openings that have dark red in the middle are approximately 130' wide (2x 66', or distance to the gap edge.

Individual gaps are not delineated or quantified with *F(t*). Delineating gaps requires subjective decisions on what constitutes a gap and where it "closes", especially in low canopy cover forests. Gap size distributions also tend to have sharp breaks that can introduce complications when comparing them across plots, especially with small plots. Instead, *F(t)* has no subjective settings and is a smooth distribution. *F(t)* quantifies what percent of the plot is greater than a specified distance away from a tree. It thereby quantifies the total amount of "open" area in a plot and distinguishes whether the total amount of opening, the inverse of canopy cover, is distributed in many small openings or fewer, larger ones. The background coloration in figure 12 show a graphical representation of the open space distribution. Many ecological processes such as regeneration and growth of shade-intolerant species (York et al. 2004), insect spread (Fettig et al. 2007), and crown fire spread can be related to distance from the nearest tree, or gap edge.

VII. Links to Companion Tools and Documents

A number of tools and documents have been developed for the ICO method. Contact Derek Churchill if you have any problems downloading these documents: derek@stewardshipforestry.com

1. QuickMap Tools: https://www.dropbox.com/s/l2rvd1cxctqrwvy/Arc_tools.zip
    a. Instructions for ArcTools
    b. QuickMAP.zip folder with ArcPAD Template
    c. Arc Toolbox folder for analysis in ArcMAP.
    d. Excel analysis (tool): Contact Derek for this document.

2. Monitoring datasheets (For cases when the ArcPAD template is not used or for backup): https://www.dropbox.com/s/x50cbei48dy889e/ICO_Monitor_datasheets_Nov13.xlsx

3. Prescription Development Excel file (Contains Rx development and tracking sheets for marking): https://www.dropbox.com/s/5a8efk1h90ivbd9/ICO_Rx%20_mark_datasheets_Nov13.xlsx

4. Future Tools. Check with authors regarding Android tablet and phone app for tracking during marking and monitoring.

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