The ICO Approach to Restoring Spatial Pattern in Dry Forests

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 restoration prescriptions and/or monitoring. 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. (2013), in which we compare the ICO method to standard basal area and spacing-based Designation by Description prescriptions (Fig. 1). Since then, we have worked with managers to implement the ICO approach on a number of ownerships. The method is now fully operational and numerous sales have been marked, sold, and cut. The method is still evolving and this document will be updated in the future. Comments and feedback are welcome!

Introduction

The ICO method is a stand-level approach to restoring 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). Many managers and stakeholders across the interior west have an intuitive understanding that, historically, dry forests were not uniformly spaced, and that "clumpy-gappy" patterns played an important functional role in these forests. Scientifically, there is broad consensus that to increase resilience, stand-level restoration treatments should seek to restore the range of patterns found in historic forests (Allen et al., 2002; Covington et al., 1997; Franklin and Johnson, 2012; North et al., 2009; Perry et al., 2011; Stephens et al., 2010).

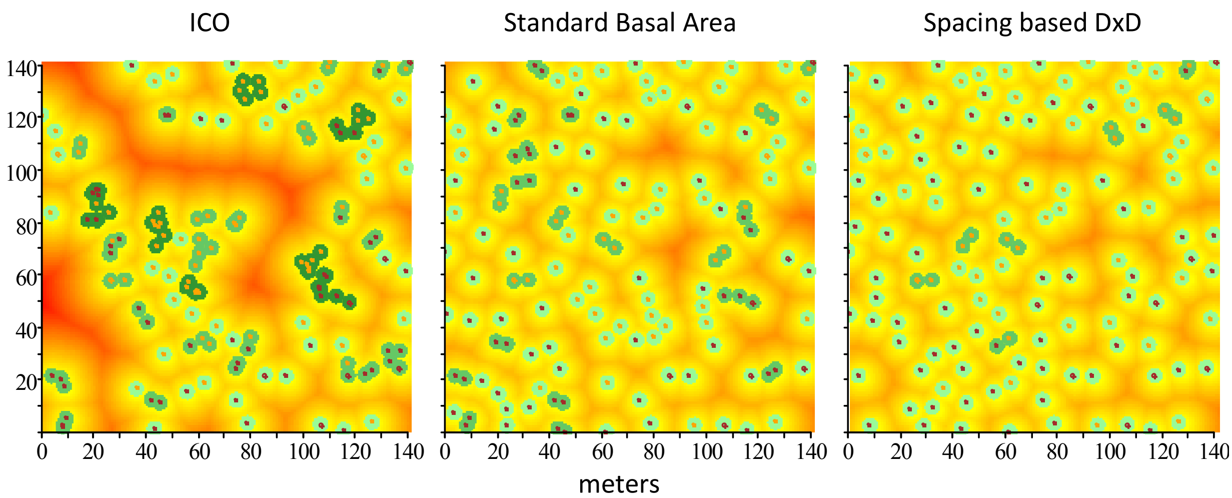

Figure 1. Five acre stem maps comparing ICO, basal area, and spacing based DxD prescriptions from Churchill et al. (2013). Darker color green indicates large sizes of tree clumps. Background yellow, orange, and red color indicates the distance to the nearest tree and openings.

The ICO approach originated from the challenge of translating the general goal of a "clumpy-gappy" pattern into marking guidelines. In developing the method, we sought to balance the needs for (1) concrete, ecologically based targets for spatial pattern that can be objectively monitored, (2) sufficient flexibility to work with current stand conditions (e.g. tree condition), and (3) operational simplicity and efficiency. We also have found the method to be a valuable tool to monitor whether patterns created by any treatment approach are consistent with reference conditions.

As typically implemented, the ICO method uses reference stands to generate spatial targets for prescriptions. Targets are expressed in terms of the number of widely spaced individual trees and tree clumps of different sizes. 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 typically obtained from stem map reconstructions of historical conditions or current forests in un-harvested areas with minimally altered or restored fire regimes. Stem maps from a particular 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). 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 in a user friendly format. A sampling method is also being developed that eliminates the need for a full stem map. Obtaining the necessary reference data to implement the ICO method is covered in detail in this document.

The ICO method has four basic components that are covered in the following sections. If you already have reference information, you may wish to focus on sections C and D.

A. 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 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.

B. 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. 3). 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 some forest types in northern Arizona (Abella and Denton, 2009; Sánchez Meador et al., 2011), the eastern Washington Cascades (Churchill et al. 2013), and the northern Rockies (Larson et al., 2012). **If you already have stem map data that has been quantified using the cluster algorithm, you may wish to skip to section C.**

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. 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 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 1.

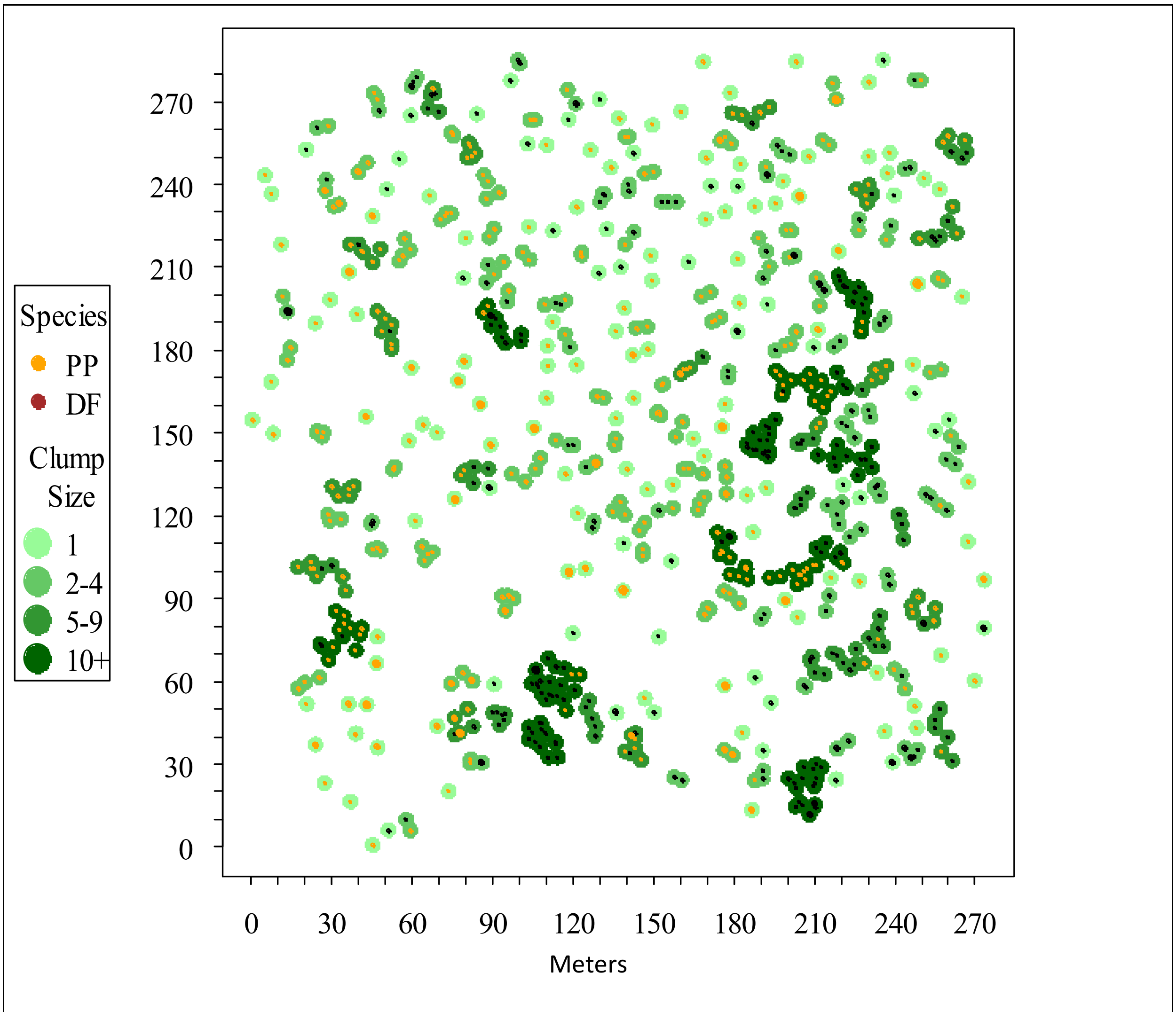

Figure 3. A ~13 acre stem map of pre-settlement trees near Naches, Washington. Three meter radius tree crowns are projected around each tree to illustrate formation of clusters using the Plotkin et al. (2002) algorithm.

B.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 stem maps should come from forests 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 accomplish this is to use climate analog reference conditions—use reference sites that have current/past 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) and are not considered further here.

B.2 Site selection criteria for new reference stem maps

After a pool of candidate sites have been identified using the general criteria outlined in section 4.1, a series of additional screening criteria are applied. From experience and simulation analysis we have found the minimum size for quantifying patterns of individual trees and 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.

- 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.
- 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.

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

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

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. 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 intertree 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 4: 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 5: 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 (Everett et al., 2007; Fule et al., 1997; Taylor, 2004).

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 2-3 people. Productivity depends on pre-settlement tree density, current understory density (which affects line of site distances and efficiency of surveying measurements), slope, and the mapping methodology being used. As crews become proficient in the required skills productivity will increase. A new method to sample clump and opening size distributions without installing full stem maps is currently being developed. Because this method is under development we do not describe it in detail here; additional information is available upon request.

B.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, the 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 cluster if they are within distance *d* of at least one other tree in the cluster, as measured from tree pith to tree pith. There are no constraints on the shape of clusters; they may take any form as long as all trees link to at least one other tree in the cluster. Clusters 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 clusters 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 "Cluster Table". This is the proportion of trees in different sized tree clumps (or clusters) at different inter-tree distances (*d)*. The cluster table associated with the stem map in figure 3 is shown in table 1. Instructions for implementing the Plotkin algorithm in ArcGIS are presented in Box 1. The method has been programmed in the statistical program *R* and the code is available upon request.

Table 1: Cluster 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	15-20
1	0.92	0.07	0	0.01	0	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	0
3	0.56	0.19	0.12	0.06	0.04	0.01	0	0.01	0	0.01	0	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	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	0.02	0.04
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	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	0.02	0.27
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	0.02	0.34

A single, maximum 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 (Graham et al., 2007; Long and Smith, 2000). 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 2). 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 intertree distances that will be used in the field (e.g. 4,5,6,7 m).

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. 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 1. 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 (area, mean dbh, species composition, etc.).

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.

<u>B.5 Quantifying within-stand patterns: targets for large openings</u>

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" (Figure 6). Prescriptions that leave significant proportions of trees in clumps will, by necessity, 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 clearly specified in prescriptions.

Methods to quantify size distributions of openings from reference stem maps, as well as from LiDAR or imagery from active regime sites, and translate them into prescription guidelines are still being developed and refined. These methods will be included in future updates of this guide.

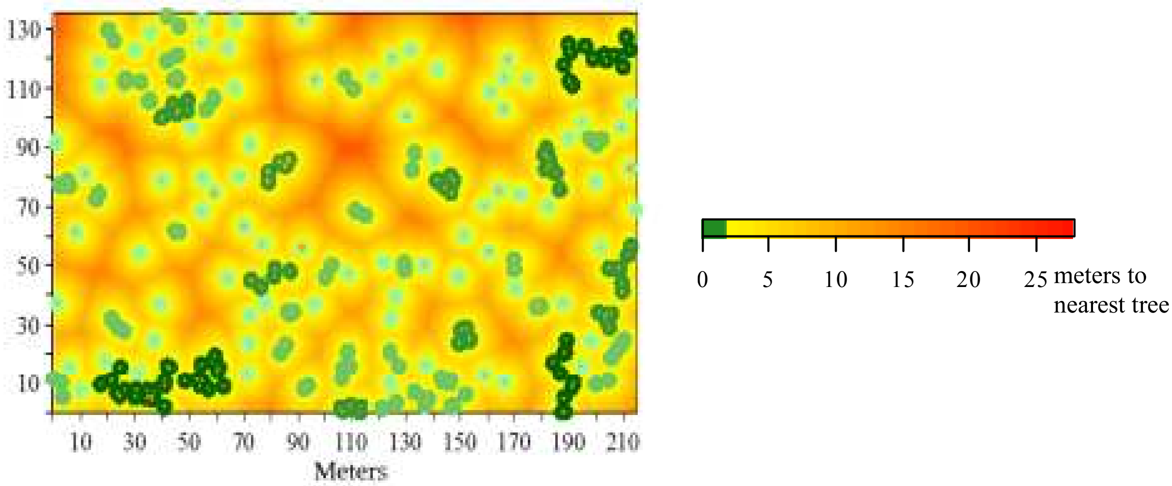

Figure 6: An ~8 acre stem map of pre-settlement trees in the Black Hills area of the former Klamath Reservation in central Oregon Background coloration indicates the distance to nearest tree or gap edge from the centers of a 1m cell grid- a graphical representation of the empty space function. The areas colored dark orange in plots are areas that are approximately 15 m (50') from the nearest tree or gap edge.

C. Prescription and Marking Guide Development:

The goal of the ICO method is not to recreate the exact pattern and density of historical forests, but to ensure that a mosaic pattern of individual trees, clumps, and openings is created that is within the range of historic conditions. Given the wide range of patterns found in reconstruction studies, there is no optimal or correct pattern for an individual stand. As with any silvicultural approach, a combination of quantitative information and professional judgement will be required in developing prescriptions using ICO method. The following steps lay out the process:

C.1 Identify thinning vs. other treatment areas within the stand

In most restoration treatments, not all the stand will be thinned with the general prescription, but instead given a different treatment. These may include areas left as untreated “skips” (e.g. riparian buffers, dense multistory patches left for small mammals, snag or downed wood patches, mistletoe patches, pole sized patches left to break up sighting distances, etc.), large openings or heavy thin areas (e.g. removing conifers around aspen clones), or special treatments for root rots etc. Guidelines for the location and treatment of these areas should be developed first. 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. densee overstory skips , or clumps of trees with mistletoe that need to be isolated). Pre-settlement trees found in the general thinning area should be counted towards clump targets. Determining the appropriate number, size, and location of these special treatment areas can be challenging, but is often dictated by existing regulation, wildlife needs, operational constraints, or forest health considerations.

Large openings can be prescribed based on the size distributions found in reference stem maps or functional objectives such as guidelines for specific wildlife habitat needs, snow retention, fire behavior, or light requirements of desired regeneration. The expected creation of openings from prescribed fire and other disturbance processes should also be factored in. For example, in a young stand with areas of root rot that will undergo prescribed fire, few large openings may be prescribed under the expectation that natural processes will create them over time. In an older stand where increasing the proportion of shade intolerant species is a goal, a greater number of larger opening may be advisable.

C.2 Choose the Inter-tree Distance

Determine a maximum inter-tree distance (*d*) that will define your clumps. At described above, we have used the distance at which the crowns of the trees will interlock when the trees are mature. This distance can vary from 15 to 23', depending on site productivity of the stand. We suggest 20' (tree face to tree face) as a default distance, but this should be field tested. Trees are members of the same clump if they are within the specified distance of at least one other tree in the clump. Individual trees are those with no neighbors within the distance. 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 spacing found in historic forests and may not be as suitable for some functions, their canopies will still eventually form clumps.

C.3 Obtain and summarize reference stem maps

Ideally, a table summarizing the range of reference conditions in your area is available (e.g. table 2 below). If not, instructions for developing one are provided in section 4. If you have a full cluster table (table 1), proportions for clump sizes should be lumped into four or five bins for operational simplicity. We use 4-5 bins: individual trees, small clumps (2-4 trees), medium clumps (5-9 trees), large clumps (10-20+ trees). Note that when instructed to leave a large clump (e.g. 10-20 trees), we have found that 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.

Table 2: (This table is repeated from page 11). 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.

		Clump (Bin) 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		

C.4 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, a low, moderate or high clumping target must be selected for individual stands. Then, select the row with your inter-tree distance and pull out the target clump proportions for each bin size (Table 3):

Table 3: An example of target clump proportions for an individual stand. Data is from high clumping level at 20'

	Clump (Bin) Size (# of trees)				
Distance	1	2-4	5-9	10-15	16-20
6m (20')	0.25	0.30	0.25	0.10	0.10

To set targets for individual stands, consider the following:

- Direction from landscape analyses. Structure stage targets for the stand will influence the desired type of pattern.
- If surrounding stands have been simplified by past thinning, consider a high clumping level.
- Assess the number and clumping levels of live old trees in your stand. The clump percentage targets should accommodate retaining existing old trees.
- In stands with few old trees, assess any evidence of historical tree patterns (live old trees, old stumps, old snags & downed logs) to determine what the largest clump size was and the approximate percentage of trees in large clumps. These historic conditions can inform what that site supported.
- 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.

C.5 Determine density target for general thinning area

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. The target must be converted to TPA for the ICO method. To convert from BA to TPA, first estimate the QMD of the average leave tree post thinning and then use the following formula: Target TPA = Target BA / ((QMD)^2 * .005454). For commercial thinning, the target should be for trees greater than the merchantability standard (e.g. 5" dbh) and should include old trees. For pre-commercial stands, a lower diameter cutoff should be used.

C.6 Generate clump targets for the whole unit:

Using your target TPA and target clump proportions, follow the steps below to generate clumps targets for the treatment unit (See table 4 for an example).

1. Multiply the percentages for each clump size by your leave tree TPA target to get the target number of trees per acre each clump size.
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.
3. Multiply the clump per acre targets by the total stand acreage to get clump targets for the whole unit. 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 5-20%, 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 4. Calculating clump targets for a unit using the ICO method

	Clump Size (# of trees)				
	1	2-4	5-9	10-15	16-20
Target Clump Percentages	0.25	0.30	0.25	0.10	0.10
Trees per acre (Target TPA 40)	10	12	10	4	4
Clump target per acre	10	4	1.4	0.33	0.22
Clump target per unit (Unit acres = 20)	200	80	28	7	5

C.7 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 2. 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, large branch platforms.

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

- Mistletoe patches: 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.
- Snags/Down wood skips**:** Protect snags > 20 inches with a no-cut buffer (~30' radius).
- Create 2 large openings: 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
- Visual and Regeneration skips: 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)

- Riparian buffers: 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.

D. Implementation and Monitoring

D.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. 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. It is critical that markers work with existing stand conditions and the leave tree criteria to locate clumps.

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.

D.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 7: Marking out clumps and real time tallying of clump totals. 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 lay 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 10-30 acre sub-units for marking so that marking crews can track their clump totals within a reasonable amount of area. If breaking up units is not practical, 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. The main tally person can then periodically check progress toward the clump targets 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. Alternatively, 1/10th – 1/5th acre fixed area count plots, or variable radius plots for BA targets, can periodically be put in to ensure that the overall density target is being met. 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 can be 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. Contact the authors for sample tracking sheets. 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 goal of the method is not the clump targets per se, but a mosaic pattern of individual trees, clumps, and openings within the envelope of historic conditions. 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.

D.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. Contact the authors for ideas on how contract compliance could work with a DxP approach. The ICO approach will not work with a straight DxD approach (Designation by Description).

D.4 Monitoring treatment effectiveness

Stem-maps can also be installed by agency staff or stakeholders 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. The Plotkin et al. (2002) algorithm can be used to quantify clump size distributions and the F-test used for openings (see Churchill et al. 2013). The size distribution of trees in different clump sizes can also be compared to reference plots by producing a cluster table with basal area proportions instead of trees per acre. Ideally, a set of reference stem maps exists to compare the treated patterns to. Additional spatial pattern metrics can be also used (Larson et al. 2012).

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